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87

Conference Proceedings

5th International Symposium "RE-WATER Braunschweig"

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Integrated Concepts

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Preface

Integrated concepts

The 5th International Symposium “RE-WATER Braunschweig” focuses on "Integrated concepts". Integrated concepts for water and wastewater management involve not only technical aspects of wastewater reuse, but the merging of diverse areas such as governance, health risks, legal regulation and public acceptance as well as other aspects of water policy. The implementation of integrated water and wastewater projects will result in the long-term sustainability of our water supplies. However, the above mentioned complex connections have equal influence on both the benefits and challenges of water reuse. Challenges experienced by water reuse projects may include the demand for innovative technologies, technology transfer and implementation of novel applications as well as the need for public education and increased public acceptance.

This symposium will deal with integrated planning and evaluation of water structures in settlement areas to be able to find a better balance between human needs and ecological necessities in the water sector. Furthermore the use of novel wastewater collection and cleaning systems will be presented. A special focus is put on the reuse of treated wastewater as a promising strategy to relieve water shortages and to protect natural resources. International examples for industrial and agricultural reuse of treated wastewater will be given. Hygienic aspects and nutrient recycling play an important role especially in the area of agricultural reuse. Therefore, topics such as micropollutants, disinfection and nutrient recovery will be discussed.

The symposium is organised by the “Stadtentwässerung Braunschweig GmbH”. Cooperation partners are the Institute of Sanitary and Environmental Engineering of the TU Braunschweig, the Berlin Centre of Competence for Water and the “Abwasserverband Braunschweig”. Further information and a detailed timetable under www.re-water-braunschweig.com

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Growing a City for 1,000,000: Master Plan for the City between the Forest and the Ocean, Senegal

Vanessa Miriam Carlow

Technische Universität Braunschweig, Institute for Sustainable Urbanism

Abstract

Much of the world is currently witnessing urbanization of a hitherto unprecedented pace and scale. While the phenomenon of urbanization in the African context is much discussed, less attention has been paid to what kind of built environments are being produced. In many cases, the pressure to build entire cities very rapidly from scratch has resulted in unethical developments, often by foreign contractors, resulting in places without proper provisions for basic infrastructure such as water, sanitation, or electricity, and built without involving the local communities or proper consideration of the local context.

Greater Dakar, the capital of Senegal in West Africa, is facing a boom in its urban population. This project investigates strategies to “grow” a new city for up to 1 million inhabitants, based on five design principles: the City for Everyone; the City of Sustainable Mobility; the 5-Minute City; the Blue, Green and Healthy City; and the City of Distinct Identity.

The central research question that is being addressed by design is how a very large city can function in a highly sustainable manner, from ecological, social and economic perspectives. This includes the question of how such new settlements can grow and mature in a controlled way, while also maintaining and developing its own distinct identity, and how a new settlement for a population of 1 million can be provided with water.

1 Introduction

Senegal has seen a tremendous growth in population in recent years. According to the UN (UN, 2013) the population increased from 10.7 to 13.7 million between 2003 and 2012 – a 28% increase in less than a decade. This trend is projected to continue.

As one of the proactive reactions to this population growth, the national government has tendered several projects for the construction of up to 125,000 houses. With average household sizes of six to eight people, such a city would house up to 1 million inhabitants. With space being scarce on the peninsula on the western most tip of the continent of Africa, the master plan accordingly recommends a city for up to one million people on a site to be opened for this new development. Instead of the pre-conceived image of this new settlement consisting of mainly single-family homes, with the project proposes a dense, compact and integrated planned city.

Figure 1: Rendering of City between the Forest and the Ocean

This is to counteract a number of unethical developments the African continent has seen in face of high development pressure. In recent years, entire cities were built into deserts without proper water or electricity supply, and also without identity and without the involvement of the local work force, thus devoid of benefit for the local communities. These so-called “ghost towns” (Hulshof, Roggeveen, 2015) were mainly built by foreign developers, for example by Chinese consortia. According to Hulshof and Roggeveen, this represents a massive geopolitical shift in which foreign investors come to Africa for large housing and infrastructural construction projects, bringing not only their investments, but also their workers, equipment and building culture, to receive resources like oil or arable land in turn.

The physical results of these construction projects can be considered the symptoms of an un-integrated, un-sustainable and un-ethical approach to planning. With the master plan for the City between the Forest and the Ocean, a more integrated and pro-active approach to developing the region and fostering the wellbeing of its population is proposed.

With the five strategies “City for Everyone”; “City of Sustainable Mobility”; “5-Minute City”; “Blue, Green and Healthy City”; and “City of Distinct Identity,” a flexible backbone is laid out for the sustainable growth for a city with up to 1 million inhabitants.

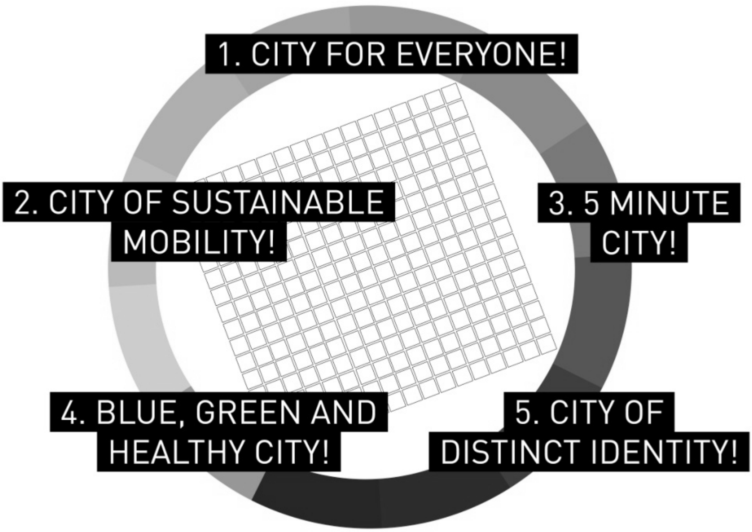

Figure 2: Sustainable City Principles

2 City for Everyone

“City for Everyone” represents the social agenda of the development strategy. The idea is simple: No one shall be excluded on the basis of her or his gender, beliefs, cultural background, or income. This social goal is reflected in the design by the mix of functions and types of housing. Accordingly, the city is marked by its wide offering of different kinds of housing, work places, and facilities to attract a large diversity of people from different social strata. The intention is that by mixing types of housing and functions and thus people, the overall need for transportation in the Dakar region is reduced, diverse communities are fostered, social disparities are mitigated, and the overall quality of life in the area is improved. With its parks, the beach, the hospitals, university, and educational and cultural institutions, the city invites visitors from the outside. With its water treatment and waste handling facilities it also provides work opportunities for already existing communities in the region.

3 City of Sustainable Mobility

Set between Dakar and the new Blaise Diagne International Airport currently under construction, Diamniadio has great location potential as the core of a new city. This new city can function as an overspill area and a complimentary town to Dakar. Diamniadio is connected to Dakar by the national road, toll way, and rail. Taking advantage of existing infrastructure allows to use the location’s existing potential. Building on the town of Diamniadio as the core for a new city relieves Dakar of the high development pressure it currently faces, as well as utilizes the large economic potential the development of the airport entails.

However, the site around Diamniadio is not a tabula rasa. A satellite image helps identify existing settlements and valuable natural elements, such as agricultural land, vegetation, ravines and water networks. In the master plan, these elements are preserved where possible and integrated into the new city in order to enhance its distinctive identity. Citizens who are already in the area should benefit from the new development, rather than being dislocated by it.

Figure 3: Regional Analysis

4 The 5-Minute City

The City between the Forest and the Ocean is tuned to the needs of pedestrians and cyclists. To accomplish this, the “5-Minute City” is used as the basic urban module of the city. 5-Minute City means that everything an inhabitant needs in his or her daily life should be reachable within a 5-minute walk from a public transport node. At an average speed of 5 km/h, this equals roughly 420 m. This means that within the 420 m x 420 m neighbourhood module of the 5-Minute City, everything a person or a family needs on a daily basis can be found. Such daily requirements in the case of this project include: the local mosque or place of worship, childcare and educational facilities, the market or other shopping facilities, sports fields and playgrounds, a park, and possibly the work place.

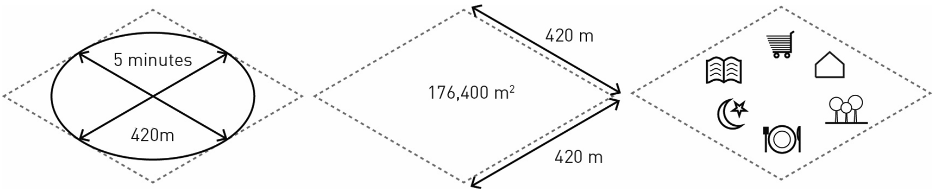

Figure 4: The 5-Minute City principle

5 Blue, Green, and Healthy City

The region of Dakar suffers from a chronic shortage of water, firstly because of overexploitation of the existing groundwater resources, and secondly because of the mismanagement of storm and wastewater. Although water is a precious resource in this region, storm and wastewater are discharged into the local water bodies in an untreated or insufficiently treated state. However, a calculation by project water engineers reveals that harvesting the stormwater runoff in the project area, as well as in the catchment area of the adjacent ravines, should be sufficient to meet a substantial part of the water demand by the new settlement – up to 60%, based on a per capita use of 60 liters per person per day. Harvested and treated stormwater runoff can be used for recreational purposes, as well as potable water.

In order to accomplish this, the project proposes a network of open spaces. This “blue and green network” helps to collect and store all rainwater, in order to gradually release it over the dry season (9 months) as drinking water after it is treated. An area analysis based on satellite images reveals existing landscape features that form the basis of the proposed green and blue network: ravines, trees, patches of forests and water. In order to improve the quality of open spaces and at the same time the resilience of the city against heavy rain events, these elements are preserved and integrated into the master plan. These spaces can be used for recreational purposes, to locally manage rainwater, and to improve the microclimate of their surroundings. In order to reduce construction costs for this accelerated-pace project, piping for handling rain or storm water management is avoided. Instead, street profiles are dimensioned and designed to direct and collect the rain and stormwater runoff in water catchment lakes.

Another important water resource that is as yet untapped is wastewater. Current water purification technology is fully capable of bringing wastewater up to drinking water standards. The treatment of wastewater to meet the standards of irrigation is today feasible with only moderate technical input, and the treatment of wastewater for irrigation of crops for food production can be optimized according to the chosen agricultural production method. The required treatment and storage facilities can be also used as recreational spaces for the public, as rainwater retention lakes and reed beds, or as wetlands in the public parks. The new city will thus make full use of the available rain and wastewater, minimizing the dependency of water supply from external resources.

Figure 5: Master plan with Blue and Green Networks, green belt and water treatment facilities

A green belt around the city compliments the internal Green and Blue network of the city. It clearly delimits the edge of the city, fostering compact development and helping to prevent the city from sprawling into its surrounding areas. The green belt itself contains recreational facilities, such as beaches and sports venues, cemeteries, water treatment and waste handling facilities, tree nurseries, agricultural land, and renewable energy farms. Towards east, afforestation marks the landscape.

6 City of Distinct Identity

Exploring the rich building culture in and around Dakar, in particular in the historic site of Touba, a few design principles become apparent that can also be replicated in the new city. In Touba, a regular grid of streets clearly delineates building plots. Most people walk. The dimensions and layout of streets and squares are of a human scale. The mosque lies in the heart of the city, often at the main intersection, its spires usually being the highest elements in the city. Private parcels are often surrounded by a wall, whereas publicly accessible facilities are often solitary buildings, surrounded by open space. But sometimes, public buildings are walled in, too. Within the grid of streets, building plots can be divided or added up according to individual needs. The surrounding landscape infiltrates the settlements: grass lands, ravines, patches of green or groups of trees. Solitary trees provide shading, orientation, and a sense of place. Sometimes, private houses form clusters with other houses. Special buildings, like schools and mosques, can be immediately recognized. Private houses look more generic, but always a bit different from one another. The proposed master plan uses these design principles to continue the existing building culture.

Figure 6: A 5-Minute City neighborhood with rainwater lake

7 Integrated Planning

As a fully-integrated design developed by a transdisciplinary team of architects, landscape architects, urban designers, climate-, transport-, and water engineers, this project is ultimately concerned with how to make a highly livable and environmentally responsible city in the context of current urbanization trends in Africa. With it's developmental strategies of City for Everyone; the City of Sustainable Mobility; the 5-Minute City; the Blue, Green and Healthy City; and the City of Distinct Identity the project ultimately strives to provide a backbone for development that is more conducive to environmentally and socially more sustainable urban growth. Specific measures include ways to encourage walking, cycling, and using public transport to get around, as opposed to owning private automobiles; taking full advantage of the existing natural environments to increase liveability and provide water, to improve the micro-climate and resilience to disasters; reducing the use of resources and energy; and utilizing buildings and other existing artifacts in the site as a part of the site's unique heritage, as objects with embedded grey energy.

In the context of today's rapid urbanization in developing economies, sustainability principles such as those described above are important tools to lay the groundwork for sustainable urban development. As demonstrated in this work, responding to site-specific challenges and project requirements while steering the project toward greater sustainability requires ingenuity on the part of an interdisciplinary design team.

Figure 7: Typical street; street profile designed for storm water runoff

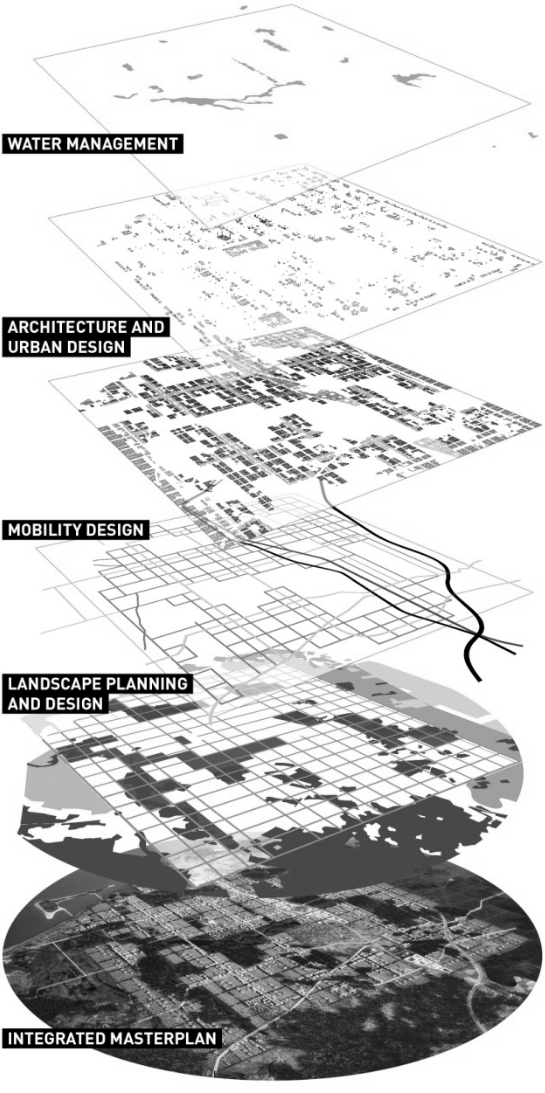

Figure 8: Layers of integrated planning

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Interlinking urban development and urban drainage? – An action manual

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Abstract

Extreme heat waves, droughts and heavy rainfall become more and more frequent and challenge our cities. In contrast to the common practice of stormwater management focusing mainly on infiltration, a paradigm shift towards water sensitive urban design with site specific strategies and measures has to be fostered. This paper presents an action manual supporting the development of site specific stormwater management measures that contribute to a near-natural water balance and at the same time strengthen the landscape and open spaces in their urban context. Interdisciplinary collaboration as well as the perception of the city as one planning area are both fundamental for a successful implementation.

1 Introduction

The mechanization of urban drainage and the resulting application of the principle of derivation have led to a loss of understanding of interdependencies between landform, water bodies as well as urban drainage and urban shape. The ongoing paradigm shift towards water sensitive urban design (WSUD) promotes the usage of different measures of infiltration and retention. However, this kind of stormwater management mainly aims at reducing peak flows and increasing base flows, but does not consider the natural water balance of each specific location. This is required according to the new technical German guideline DWA-A 102 (2015). Also increasing heat waves and droughts call for a focus on evaporation measures to raise cooling effects in such periods of heat (e.g. Henrichs et al., 2015). The evapotranspiration of a city is heavily reduced due to surface sealing, water derivation and a lack of green open spaces resulting in an evaporative cooling that is not enough to meet the needs of the city.

At the same time, the trend of urban development veered towards an integration of stormwater management facilities and the accentuation of water processes in open space design - water management acts as an impulse for urban and open space planning (cf. e.g. Stokman, 2013). However, according to Beneke (2003) the current practice of stormwater management often follows a “parcellation approach” (Beneke 2003:6) relating to small drainage units, often defined by property ownership. The result is a variety of applied measures that are detached from each other and are not connected to the logics of the watershed (Beneke, 2003). Furthermore, synergies between open space planning, urban development, climate adaptation and heat prevention are not sufficiently addressed.

Therefore, the authors call for the development of an action manual that interlinks strategies of urban drainage and urban development and thus, allows

- the consideration of the local deficits of the urban water balance,
- to foster the promotion of a water sensitive urban development adapted to local conditions and take advantage of financial as well as spatial synergies,
- the design of water infrastructure in a more resilient and sustainable way in order to be able to respond to climatic and demographic changes.

2 Action manual and application to case study

The action manual is based on five steps (figure 1). Its application to a case study in the German city Gelsenkirchen is presented.

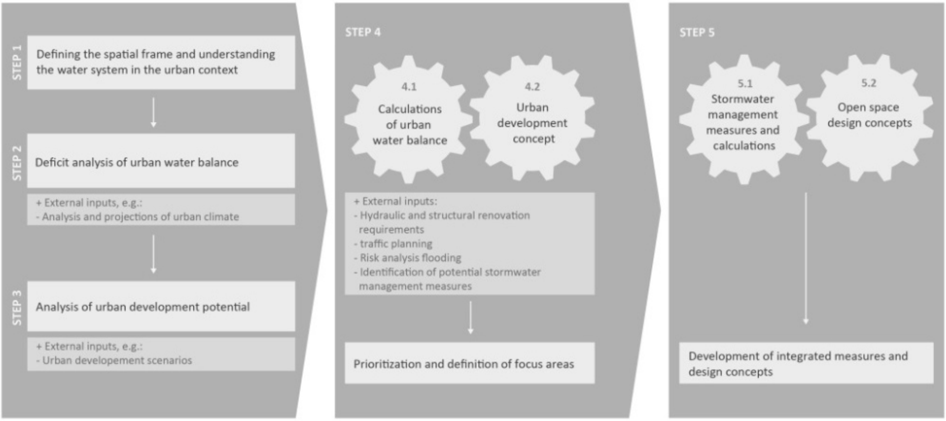

Figure 1: Action manual for a water sensitive urban design (ILPÖ/ IWARU 2015)

2.1 Step 1: Defining the spatial frame and understanding the water system in the urban context

In order to consider the water balance holistically, and to be able to plan measures accordingly, the definition of the spatial frame is an essential first step. In contrast to the definition of a project area according to administrative boundaries, as it is common in urban and open space planning, the project area in Gelsenkirchen is determined by the watersheds of three tributaries of the river Emscher. The defined area is examined regarding the correlation between the urban relief and the water system: natural aspects such as the topography, the water body and watersheds are analyzed as well as the influence of the urban context on the natural water cycle: Surface sealing, land use and the extension of the natural water system through above and underground canals play an important role.

2.2 Step 2: Deficit analysis of the urban water balance

The aim of the second step is the identification of areas with a high urban water balance deficit. Through this deficit analysis the mean annual rates of surface runoff, groundwater recharge and evaporation of the undeveloped state are compared with those of the built-up one with the help of the water balance tool WABILA. This indicates how the water balance would have to be modified in order to reach the undeveloped state (cf. Uhl et al., 2013, Henrichs et al., submitted).

$$P = ET_a + GWN + RD \quad \text{Eq. 1}$$

$$P = v \cdot P + g \cdot P + a \cdot P \quad \text{Eq. 2}$$

$$1 = v + g + a \quad \text{Eq. 3}$$

$$Sum_{Deviation} = |v_d - v_n| + |g_d - g_n| + |a_d - a_n| \quad \text{Eq. 4}$$

With P precipitation (mm/a), ET_a actual evapotranspiration (mm/a), GWN groundwater recharge (mm/a), RD surface runoff (mm/a), v (-) partitioning factor for evapotranspiration, g (-) partitioning factor for groundwater recharge, a (-) partitioning factor for surface runoff, index d developed state and index n near-natural/undeveloped state.

The calculations of the water balance for the case study are based on ALKIS-data, the mapping of land use done by the Regionalverband Ruhr, and the orthophoto interpretation of paved areas. The results are illustrated in figure 2 as the sum of deviations for a, g and v (Eq. 4) between the undeveloped and the built-up state. The water balance is always summarized for land parcels. The deviations range between 0 (natural areas) and 1,5 (highly sealed industrial zones, heavily built-up residential areas). In the case study, most of the areas with high deviations of the natural water balance are located south-east, south-west and north.

Based on a map such as figure 2, areas with a high need of application of measures that reduce the deficits of the urban water balance, can be defined.

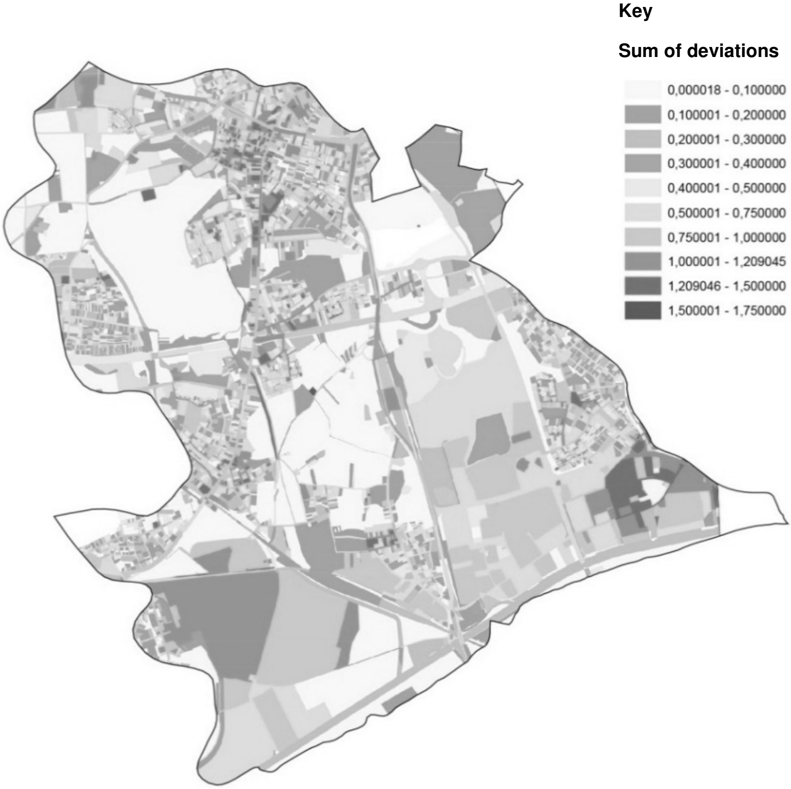

Figure 2: Resulting map of deficit analysis of the urban water balance of the case study area (IWARU 2015)

2.3 Step 3: Analysis of urban development potential

Potentials regarding urban and open space developments (e.g. extension of green links and movement corridors, creation and enhancement of green open spaces, re-structuring of traffic space, strategies for green roofs, etc.) are pointed out in step 3. In Gelsenkirchen various ideas for the urban space are already in existence and also concern the project area. However, these are related to different scales and have been developed by different city departments. Thus, an integration regarding their relevance and potentials for water sensitive urban design did not occur. Therefore, information from both, the regional land use plan and the landscape plan, as well as aspects extracted from informal planning instruments such as the regional cooperation project “Emscher Landschaftspark”, developments within the project “Zukunftsvereinbarung Regenwasser” and Gelsenkirchen’s development concept of green open spaces, are overlaid. In this way, areas which will be subject to change regarding their land use or which will be developed in terms of better connectivity are identified in the project area. Also the conversion of the Lanferbach, from an open sewage channel back to a natural stream, offers a great potential for measures that promote the integration between urban drainage and open space planning (figure 3).

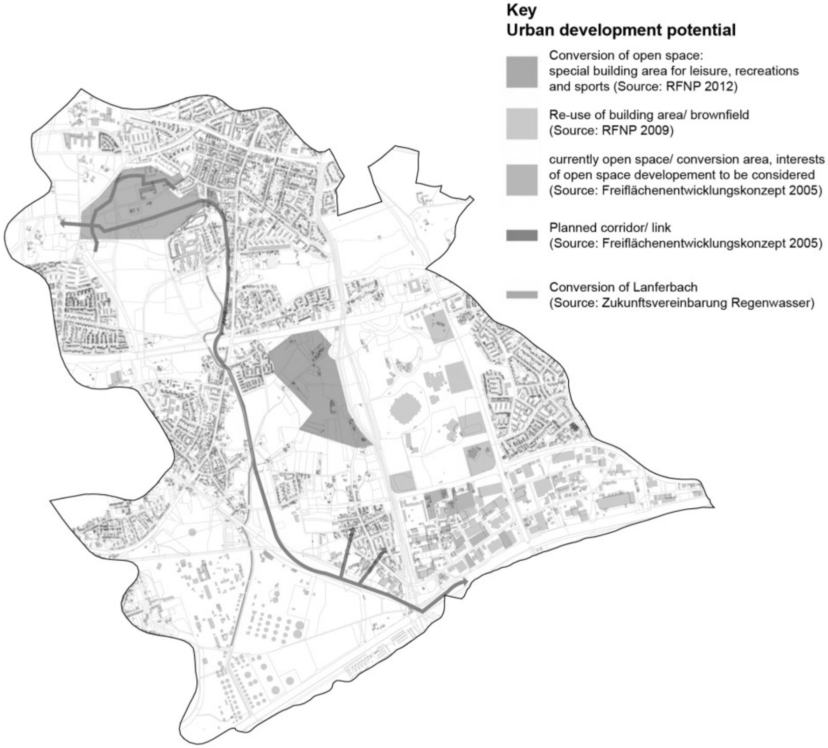

Figure 3: Resulting map of the analysis of urban development potential for the case study area (ILPÖ 2015)

Furthermore, the consideration of urban development scenarios can add significant potentials. Urban development scenarios are based on existing tendencies and project different development directions (extreme scenarios, standard scenarios) for different time horizons (short, medium and long-term). The current urban fabric is seen as a changing, perhaps also shrinking structure. This requires answering the following questions: Which changes are to be expected due to economic and demographic changes and new demands from urban society? How can water related fields of action be interlinked with those of urban planning?

2.4 Step 4: Prioritization and definition of focus areas

Step 4 aims at prioritizing and defining focus areas. Identified deficits and potentials regarding the urban water balance and urban development (step 2 and 3) are interlinked. Further aspects such as the hydraulic and structural renovation requirements, traffic planning as well as risk analysis of flooding can be taken into account at this point (cf. figure 4).

For the case study, the resulting maps of steps 2 and 3 are overlaid with maps that show the potential flood areas of the river Emscher, the depth to groundwater table and simulations of urban flood risk due to extreme rain events (annuality 50 a). Potential focus areas resulting from this overlay of aspects are discussed interdisciplinary. Great potential for synergies can be found where the need for action to solve different problems accumulates. For instance, planed urban development measures can be used as an impulse for water related measures, while water related interventions can integrate measures in order to improve the quality of open spaces. Thus, investments are used multifunctionally. In addition, areas which are located nearby those with needs for action can offer interesting opportunities to improve the water balance with the help of a combination of measures from other fields.

The preliminary focus areas are further analyzed regarding the relevant aspects. This is the basis for a prioritization and final definition of the areas to be focused on.

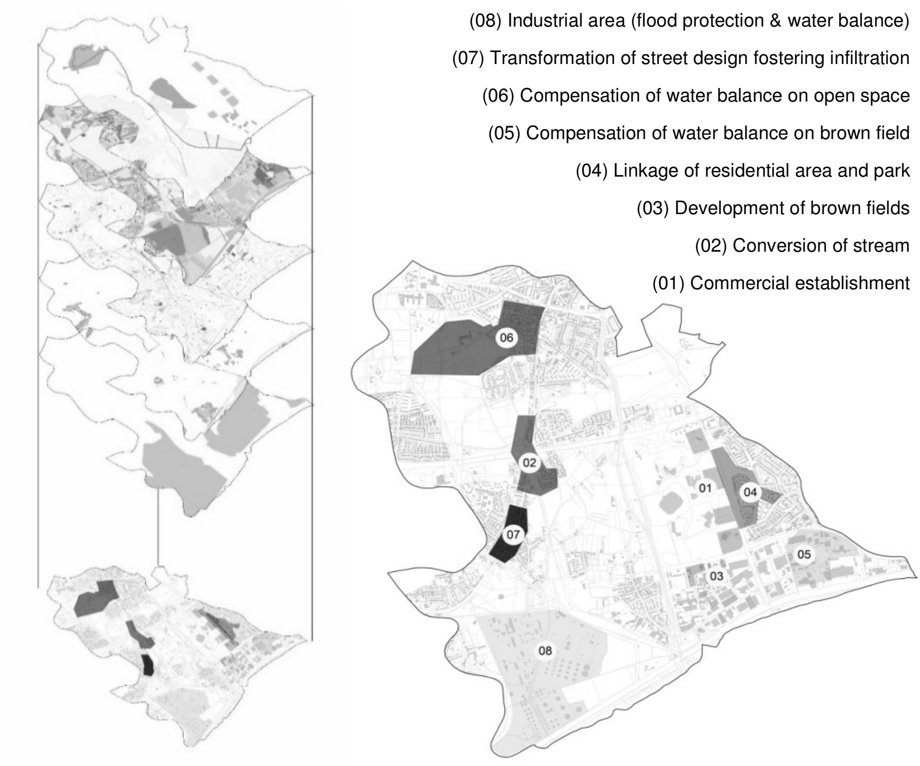

Figure 4: Overlay of resulting maps from steps 2 and 3 with further aspects relevant to the project area and map showing the preliminary focus areas (ILPÖ/ IWARU 2015)

2.5 Step 5: Development of integrated measures and design concepts

An intensive communication and exchange of ideas between the disciplines of urban drainage and urban and open space planning is necessary in order to develop multifunctional measures and design concepts for the focus areas. In the research project a transferable catalogue of measures is developed, which summarizes the opportunities and highlights the potential of site specific design strategies. The catalogue provides information about which measure of decentralized stormwater management supports which aspect of the water balance (evaporation, infiltration, surface runoff). In addition, reference projects illustrate how stormwater management measures can be designed in an appealing and multifunctional way.

The water balance tool WABILA offers the opportunity to calculate the long-term effects of different stormwater management measures on the water balance. Hence, the developed design concepts can be tested and improved in an iterative process. With the help of the catalogue in combination with WABILA, design strategies and concepts are developed for selected focus areas of the case study.

3 Conclusion and outlook

The developed action manual intends to support an interdisciplinary collaboration by synchronizing working steps and identifying points of interaction between the disciplines urban drainage and urban planning. Different measure and development scenarios can be compared through a partially “automated” process. As a result, this integrative planning process creates a new basis for creative solutions that maximize synergies and develop the urban system in a more resilient and sustainable way based on a considerate handling of the urban water balance.

4 Acknowledgement

The research work and software development are part of the joint research project “Die Stadt als hydrologisches System im Wandel” (SAMUWA) and is supported by the German Federal Ministry of Education and Research (BMBF, FKZ 033L071J and 033W004A, Fördermaßnahme INIS, Förderschwerpunkt NAWAM).

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Innovative de- and semi-centralized water infrastructures – opportunities for water supply and wastewater companies

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Abstract

This paper identifies strategic options and business opportunities of water companies in German municipalities in the context of innovative water infrastructures. The assumed implementation of innovative water infrastructures (e.g. grey water recycling or heat recovery facilities) will contribute to combinations of heterogeneous de-, semi-centralized and central infrastructures. In other words: there will be a side by side of different technologies and configurations of water facilities and networks. The findings, based on interviews with water company officers, show that coordination between central and de-/semi-centralized water infrastructures is as essential as the management of the interlinking between different infrastructure systems of public services. The role and duties of water companies and utilities become more challenging. In order to capture the opportunities of innovative water infrastructures, probably new organization models and structures have to be developed on the local level.

1 Introduction

Many German water management companies are facing major challenges: They have to react to impacts caused by climate change, rising energy prices or demographic change (Hiessl et al. 2012, ATT et al. 2015, Fahrenkrug et al. 2015, Kluge/Libbe 2010). For example, water demand varies in a changing way over time (short and long term) and spatial contexts. Infrastructures (networks and facilities) in regions or cities with population decrease suffer under-utilization (Koziol et al. 2006). Furthermore, micro pollutants in wastewater demand more sophisticated treatment technologies (Hillenbrand et al. 2015). In sum, the costs per capita for operating the infrastructures and services will rise. The impacts of the above mentioned driving forces take effect in very different ways regarding to spatial circumstances and conditions – on a regional level as well as in different urban quarters. At the same time, integrated and innovative water infrastructures are available with the potential to adapt urban water management to changing conditions (Bieker 2009, DWA 2008, Staben 2008). In the current project of the netWORKS research association (www.networks-group.de/en) the following integrated infrastructures are in focus: heat recovery from wastewater, grey water recycling and reuse as service water, and black water separation for efficient fermentation and biogas production. These integrated systems are often designed as de- or semi-centralized water infrastructures whereas traditional water supply and wastewater systems are usually designed as centralized infrastructures operated by one company in charge.

This paper addresses the analysis of strategic options and the development of business opportunities of municipal drinking water and wastewater companies against the background of the possible implementation of innovative water infrastructures in the future[1]. The findings presented in this paper are based on several expert interviews and a scenario workshop with representatives of municipal water and wastewater companies in Germany, part of the research activities of the netWORKS research association[2].

2 Examples of innovative water infrastructure

In the current project of the netWORKS research association, different configurations of water infrastructure systems have been designed for different types of settlement patterns ("Siedlungsstrukturtypen") in German cities. These water infrastructure systems are configured out of a set of modular components (see Bieker 2009, DWA 2008, Staben 2008), which can be organized by mass flows (e.g., rainwater, drinking water, black and grey water, service water, heat) and their spatial dimension (building, district, town).

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[1] A completely different access to future "business opportunities" of water supply and wastewater companies choose Hoffjan et al. (2014). They based their argumentation on the assumption of „increasing competitive pressure" and „enhancing efficiency".

[2] The current netWORKS research association project "Intelligent integrated water management solutions in Frankfurt am Main and Hamburg" is funded by the German Federal Ministry of Education and Research (BMBF) within the funding measure "Smart and Multifunctional Infrastructural Systems for Sustainable Water Supply, Sanitation and Stormwater Management" (INIS).

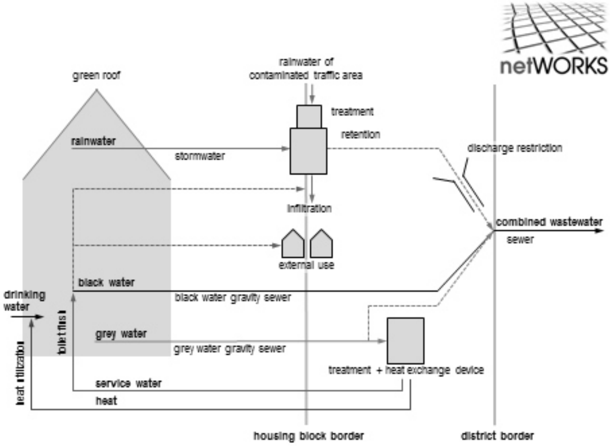

Figure 1: Example of grey water recycling and heat recovery on the district level

Source: Own illustration by the netWORKS research association

The following elements of innovative water infrastructures are in focus:

- heat recovery from wastewater and its use for hot water generation and space heating,
- the collection, treatment and reuse of separated wastewater flows like grey water (domestic wastewater without toilet flushing) or rainwater for service water[3] purposes,
- the collection and treatment of black water for efficient fermentation and biogas production, and
- de-centralized rainwater management.

Independently to the focus on water companies in German municipalities in this paper, it may be worth to consider the mentioned innovative water infrastructures in regions and towns in Europe with specific demand of amplification and the construction of new water supply and wastewater disposal solutions.

3 This technology is said to have future business potential (European Commission 2014).

A clarification has to be made at this point: The above mentioned innovative, often de- or semi-centralized infrastructures will not totally replace traditional infrastructures of water provision and sewage disposal (incl. treatment). But, under some spatial, socio-economical, financial and ecological circumstances and conditions, they have the potential to amend and enrich the traditional shape of water infrastructures. In future – this is my thesis – de-, semi-centralized and centralized infrastructures will be combined, and there will be a side by side of different technologies, configurations and systems of water infrastructures. So, I am not arguing in a simple dichotomy of de-centralized (innovative) versus centralized (traditional or conventional) water infrastructures.

3 Strategic options and business opportunities for (municipal) water companies

If the above mentioned integrated and innovative water infrastructures will become more frequent and gain considerable part in heterogeneous water infrastructure configurations in the future, the boundaries of the systems will shift and new interlinking between infrastructures and services will come up. Probably water supply and wastewater services "move together", if grey water is treated and commercialized as service water. Wastewater and energy supply merge, when heat is recovered from the wastewater flow in the sewer. New business opportunities may arise, if instead of just one central wastewater treatment plant additionally many de- and semi-centralized plants and facilities need to be operated ("operation" may include control, monitoring of parameters and operational maintenance and surveillance).

Traditional water infrastructures are based on a uniform design of centralized systems. And usually water supply and wastewater management are separated not only on the technical dimension of infrastructures but also – at least in Germany – on the institutional and organizational level. In contrast, innovative water infrastructures are based on principles of mass flow separation and the approach of cycle of materials (DWA 2008). These principles enable possibilities to interconnect different urban infrastructure systems and services. Thus, the characteristics of innovative water infrastructures unclose new strategies for municipal water companies to handle the transformation of urban infrastructures and to benefit from its opportunities.

Assuming that innovative water infrastructures gain considerable part in heterogeneous water infrastructure configurations, the following strategic options and business opportunities for municipal water companies may show up.

3.1 Water-energy nexus

Heat recovery of wastewater and the separated collection of black water for biogas production represent two innovative technical systems, which directly indicate potentials for the water-energy nexus. Already today, some of the possible interconnections between water and energy systems are practiced: for example the actions to increase energy efficiency of wastewater treatment plants (DWA 2013). Other possible interlinking could be identified and developed[4]. Additionally, water supply and wastewater companies in Germany may take advantage of the dynamics of the so called “Energiewende” (transition of the energy system) and offer their services and potentials (DWA 2013). Based on the above mentioned innovative water infrastructures, the following options have been identified in this context:

- Production and supply of electric power and heat on the central wastewater treatment plant

Today, many operators of wastewater treatment plants use the energy produced on the plant (biogas and heat) for the energy demand onsite. 90 % of the biogas produced on wastewater plants by sludge and biomass fermentation is used directly on the plants (Destatis/DWA 2015). The prior objective is to optimize the energy efficiency of wastewater treatment plants, in order to be able to operate the plant without external energy input (energetic self-sufficiency) in the future (see Parsons et al. 2012, Haberkern et al. 2007). For this goal, in addition to the utilization of the biogas potential on the plant (which can be increased by co-fermentation of other biomass) it is possible to use the plant area to install renewable energy power plants like photovoltaic cells and wind power plants. Finally, heat can be recovered on the central treatment plant in the effluent or sludge disposal. If the energy production onsite the plant in general, or at least in energy production peaks, exceeds the energy demand of the treatment plant itself, it is possible to induct the exceeding electricity into the public network. The electric power could be used on other water infrastructure plants/facilities operated by the water company (wheeling model, “Durchleitungsmodell”) or could be sold to third parties like the local energy supplier for instance.

- Offering the sewer to third parties for heat recovery activities

As mentioned before, heat can be recovered at the central treatment plant or in different spots in the sewer. This configuration is represented in the following figure:

[4] See, e.g., in Germany the funding program "Future-oriented Technologies and Concepts for an Energy-efficient and Resource-saving Water Management – ERWAS” launched by the Federal Ministry of Education and Research (BMBF) (https://bmbf.nawam-erwas.de/)

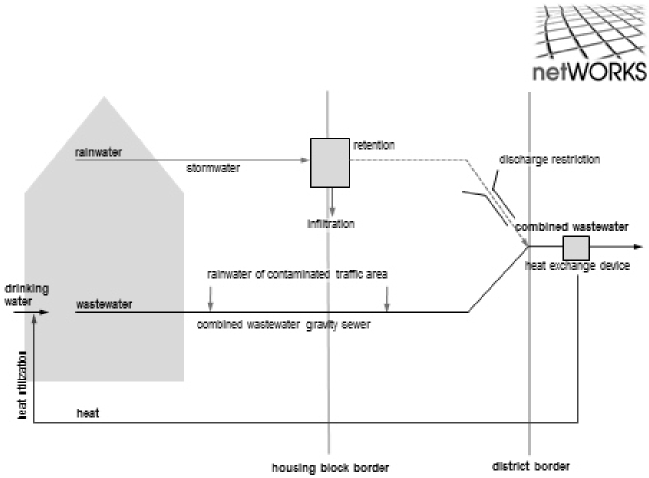

Figure 2: Heat recovery in the public sewer
Source: Own illustration by the netWORKS research association

The estimated thermal and economic potentials of heat recovery of wastewater flows vary in literature (DWA 2013, Grazer Energieagentur 2007) and among the experts, which have been interviewed in the context of this research project. Heat recovery of wastewater seems to be an option, if the thermal potential is significant (high and continuous flow of wastewater, temperature) (heat source) and if at the same time a reliable heat customer (heat sink) is situated close to the sewer and the heat recovery facility. Due to these pre-conditions there is a limited number of “hot spots” for heat recovery in the public sewer network.

In case of the water companies are interested in starting activities in heat recovery of wastewater in a proactive way one possible option may be the systematic identification of the heat potential in the sewer network and the creation of a GIS-based map indicating the hot spots for heat recovery. By knowing the possible spots in the sewer network with significant potential, the water company could motivate companies in the heat supply market to implement and operate facilities.

One possible model could be to bill the water companies expenditure and efforts for the provision of the sewer (e.g., in control, maintenance or surveillance). The water company defines exactly where to implement the heat recovery plant and the further technical specifications. Another model could be to rent parts of the sewer to heat companies, which define (under control of the water company) where and how to implement the heat recovery facilities.

In both models, the water company does not operate the heat recovery plants and does not step directly into business activities in the heat supply market (which seems to be rather a theoretical than a real strategic option). The underlying idea is to generate extra income (profit contribution, “Deckungsbeitrag”) with the company´s asset (in this case the sewer) to co-finance the activities and public services of the company.

- Sanitary environmental engineering as a player in local load management

In the context of the “Energiewende” (basically the replacement of fossil energy by renewables) it is one of the mayor challenges to secure the stability and flexibility of the power system (BMWI 2015). Intelligent management of electric power in local and regional networks is one important option to achieve flexibility in the power network system.

Wastewater treatment is one of the principal energy consumers in municipalities, and the specific profiles of the daily power demand of water supply and wastewater differ: power demand on the wastewater treatment plant is higher in daytime, while the demand for pumping and treatment of drinking water is higher in nighttime. Furthermore, an increasing capacity of energy production units (e.g., block-type thermal power stations) is installed on wastewater plants. And the installed block-type thermal power stations of the treatment plants can be run focused on heat or power (“stromgeführt”) and combined with other units to “virtual power stations”. Hence sanitary engineering offers starting points for local load management in electric power networks.

How and to what extent water companies can generate income and profit contribution by offering services regarding to local load management in order to stabilize local power networks, depends on two factors: 1) on the legal and institutional framework and, of course, 2) on the overall potential and support of the sanitary environmental engineering to local load management of power networks, which can only be defined in concrete contexts.

The before mentioned three options to develop new business opportunities enabled by the implementation of innovative water infrastructures indicate the necessity to coordinate activities and to cooperate with companies and stakeholders in other sectors of public services (in EU speech: “services of general interest”) like power and heat supply, but also real estate and housing, and municipal administration. Municipal water companies should consider the business models and services offered by other municipal enterprises in further public service sectors in order to identify overlaps of services and business areas. This helps to avoid (inner municipal) competition and conflicts. For example, activities of de- or semi-centralized heat recovery can generate rivalry to existing central heat networks run by the municipal energy company (“Stadtwerke”).

The importance of the local setting and arrangement of municipal enterprises and the overall governance of the municipal holdings is obvious.

3.2 Operation of de- and semi-centralized facilities

As an effect of the implementation of innovative water infrastructures, the number of de- and semi-centralized plants and facilities owned and/or operated by private stakeholders like owners of housings, real estate companies, developers, etc. will increase. Independently to the question who owns and operates the facilities, sewage treatment and disposal and water supply in Germany are public services and duties. Thus, they are necessarily under public control and specification (Tauchmann et al. 2006). In case that the heat recovery plant is planned in the public sewer, obviously the planning and implementation of this facility has to be coordinated with the local water company. Opposite to this first case, if the heat recovery plant is planned on private ground before the discharge of the wastewater form the private into the public sewer (e.g., in bigger private housing projects), the local water company has few or limited legal possibilities to intervene in the planning and specifications of this private facility.

As de- and semi-centralized plants often may be situated on private ground, the strategic question for the municipal water company is, whether and how the company can coordinate, regulate and control these plants. Many of the experts interviewed in this context mentioned the importance to bring these facilities under public coordination and control.

Today, operation, maintenance and surveillance of (de- and semi-centralized) plants and facilities are part of the “daily business” of water companies. Larger water companies offer their know-how and services in operating facilities to other, often smaller, water companies. Therefore a wide range of operator and plant management models exists, especially in the wastewater sector. In rural areas, water enterprises exercise consultancy and control of small de-centralized sewage works and wells on private grounds.

With the implementation of innovative water infrastructures and as a consequence of this a more heterogeneous design of water infrastructure, the operator and plant management models mentioned above may become more attractive and common in urban areas in cooperation between the (municipal) water company and private stakeholders. Examples for de- and semi-centralized infrastructures in the urban context are grey water recycling, heat recovery plants or block-type thermal power stations, which will become more frequent in course of the “Energiewende” also in private housings.

Water companies can take the operation and management of de- and semi-centralized facilities in different models and portfolio of services. The services can range from control and surveillance, maintenance, care, repair and restoration of existing facilities to planning, conceptual design and project management of investment projects regarding to new constructions, amplifications or modernizations.

In addition to economic opportunities of profit contributions by offering these consultancy services, the public control over correct operation of the facilities and their outcome in terms of quality and efficiency in the public services of a secure water supply and ecological and hygienic wastewater management is an important motivation to step into these business activities.

The operation of de- and semi-centralized facilities and equipment can easily be combined with other services in direct contact with customers and stakeholders (Hiessl et al. 2012): examination of the sewers on private ground, management of meters, remote readout for housing companies and other utilities or consultancy in the management of service water in industrial applications (a part of the public water networks).

3.3 Deepen the activities in mass flow separation and water resource management

Today in many German municipalities the relevant mass flows, like drinking water, stormwater and wastewater, are separated in different organizations and institutional responsibilities (see ATT et al. 2015). In chapter 2 examples of innovative water infrastructures were mentioned. They suggest an integrated view on water supply, wastewater treatment and disposal, and the management of water resources in settlements. De- or semi-centralized grey water treatment and its reuse as service water, de-centralized rainwater management or the separated collection and treatment of black water are grounded on the water cycle approach and on locally orientated mass flows. Considering these approaches and technical options it is, of course, reasonable to connect water supply and wastewater disposal and to manage these two infrastructures in an integrated manner. If grey water is recycled and reused as service water (or even drinking water), obviously “both sides” of the environmental engineering are addressed. But furthermore, it suggests the development of activities and services in preservation of water bodies and landscape: maintenance of outlet ditches (Vorflutgräben), dikes and surface water, desludging of ponds, lakes and rivers, measures of restoration / rehabilitation of rivers. In this point of view, (municipal) water companies, in addition to the technical/physical dimension of water infrastructures (“grey infrastructures”), also take the management of the “blue and green” infrastructures in an integrated way (Nickel et al. 2014). They become the central player to manage the local water resources.

4 Conclusion

It is not the place in this article to argue in a profound and broader way, if or not and to which extent innovative water infrastructures have the potential to amend, enrich or even partially replace traditional water infrastructures. But the discussion above tried to give some ideas of the potential and opportunities for (municipal) water companies regarding to a (supposed) implementation of innovative water infrastructures.

The presented strategic options and business opportunities do not exclude each orther. They are combinable. Unclosing interlinking and synergies between water and energy (heat recovery, sludge based biogas to run block-type thermal power stations) can be encouraged by business activities in the field of operation and management of de- and semi-centralized facilities. These services, plus an integrated local water resource management, enable water companies to develop a holistic approach and business model and take an important role in integrated urban planning and the sustainable development of urban infrastructures, which may end up in a broader transition process. Urban and infrastructure planning probably will become more complex as there has to be dealt an increasing uncertainty of future developments and number of stakeholders. As, e.g., de-centralized grey water treatment plants work in private facilities/buildings, they are not necessarily operated under the management of the central water company in charge, private third party agents/stakeholder show up. “Smart” coordination between central and de-centralized water infrastructures is as essential as the management of the interlinking between different infrastructure systems (water, energy, waste). With an increasing heterogeneity and number of plants and subnetworks, the complexity of steering and control of the infrastructure itself and the coordination of the stakeholders will rise. The role and duties of water companies and utilities become more challenging. Thus, the demand of competencies and know-how in public service companies for planning, management and coordination rises.

The empirical findings show, that probably new organization models and structures have to be developed on the local level. Especially in the interaction between water and energy systems it is necessary to develop organizational models that are able to capture the opportunities of innovative water infrastructures. At the same time, these models need to propose solutions to avoid conflicts with the public purposes of the municipal water companies. In some cases it may be adequate to reform the legal structures of municipal/local companies (Hiessl et al. 2012). In other cases it may be necessary to think of more fundamental adjustments and create new, probably hybrid (subsidiary) companies. For example, the creation of a specialized subsidiary company for the surveillance, maintenance and operation of de- and semi-centralized facilities may be worth to think about. Depending on the current local organizational model of provision of services of common welfare and public interest, a common subsidiary company of municipal water and energy companies could be established.

The basic idea of the strategic options and business opportunities mentioned in this article is, first, to optimize the workload of the existing resources (equipment and manpower) in the water company and, second, to gain profit contribution for the public, common welfare orientated service provision of water supply and wastewater treatment. By securing the municipal companies resources´ and know-how, local authorities keep and secure a central “tool” for locally defined development of public services, the transition of local infrastructures and the democratically based planning and development of the municipality.

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Sewage utilization instead of sewage treatment

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Newton's laws and Maxwell's equations are axioms. They are sound not just because they are straight reasonable, rather because the consequences drawn from them are equal to reality. Károly Simonyi

Keywords: sewage utilization, sewage treatment, modelling of biological filtering

Abstract

The majority of textbooks define the term of wastewater as a kind of mixture. This seemingly scientific definition, however, does not make the point: namely that mixing is not predestined but rather is caused by us. Wastewater treatment then is about separation, i.e. the restoration of the pre-mixing condition. Consequently mixing is not a wise thing to do. We don't need to forgo flush toilets but the separate collection of greywater and blackwater is profitable from the point of view of waste collection and water treatment. Blackwater cannot be transported profitably to a large distance. Therefore small, local sewage utilization and treatment units are the answer.

Sewerages have already mostly been developed ending at large wastewater treatment plants commonly known as LWWTP in English. It is difficult to implement separate collection in a densely populated urban environment. Traditional solutions still have to be taken into consideration in the future, but an emphasis needs to be put on sewage utilization instead of sewage treatment. If the total amount of sludge is conveyed following pre-sedimentation we need to provide only for the treatment of the so called decanted wastewater. In terms of this activated sludge technology or any other technology using sludge as a biofilm carrier for water treatment is excluded.

The theory of biological filtering makes it possible to make water purified without the involvement of sludge flocs. The theory also has got an axiomatic foundation, as per:

- The biofilm serving as a habitat for bacteria can stick only to a solid surface.
- Contamination to be extracted from the water (which, at the same time, is a nutrient itself) has not only to be transported to the biofilm but needs to be ingested there, as well. The optimization of nutrient supply logistics and the maximization of the surface serving for microbial colonization can be achieved at a low Péclet number.
- The biochemical process within the biofilm is regulated by the laws of the Michaelis-Menten enzyme kinetics. Microbial reproduction is described by the Monod kinetics.

The theory of biological filtering may be originated from the logistics process and the two kinetic processes building on each other. With the help of biological filtering an effective biological water treatment can be achieved in the course of which even medicine residues are filtered out.

There are several possible ways for sludge utilization. Biogas generated through anaerobic digestion is considered today an environmentally conscious way of utilization. However, we have to note that biogas contains only 60% of combustible methane while in 40% it consists of carbon dioxide. Biogas in this state of low heating value can be burnt only in gas engines at poor efficiency. Biogas needs to be purified in order to be fed into the natural gas network. Gas purification - along with the improvement of heating value - is an expensive process.

Both digested sludge and raw sludge are compostable or may be disposed with the aid of LIGNIMIX process. Both end-products are useful for agriculture. As a result of climate change there are more and more heavy rainfalls while permanent droughts are getting more frequent, as well. In order to prevent soil erosion all of us are interested in the agricultural disposition of sewage sludge. Sludge disposed to arable land is engaged in “food production”, therefore quality requirements come forward against it. Environmentally conscious use of the sewerage system is not a matter of course: it needs to be encouraged, as well. Today by charging environmental user fee just the very opposite of this is to be achieved.

Agricultural disposition of sewage sludge has extra costs. However, the area-based subsidy granted to landowners as a matter of fact ought to be paid only to those who undertake the extra costs of manure spreading in order to subdue the negative effects of climate change.

This <u>integrated approach</u> may not only allow environmental aspects to prevail but can also provide us with a source of energy and a product that can be utilized on arable land.

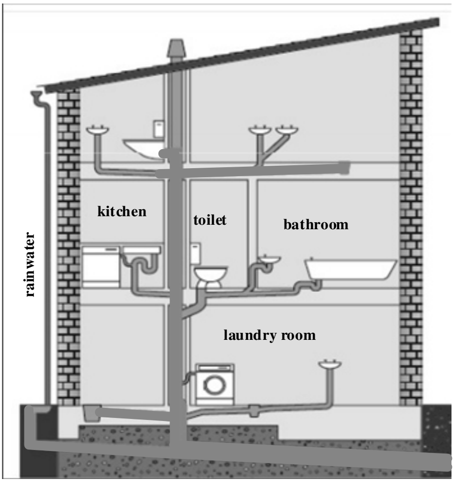
1 Sewage generation and collection

There are several definitions of the term sewage or, with other words, wastewater known. Wikipedia provides the following definition[5]:

Wastewater *is the end-product of industrial or communal water consumption; essentially it is any kind of water that has been polluted to the effect of anthropogenic impact or, respectively, its original quality has degraded.*

This explanation considers pollution as a fact, although pollution of the entire amount of water does not necessarily come forward.

We use water in the households in order to make our life easier and raise the quality of life when flush off “contaminations” generated in the flat.



1-1: Generation of household sewage - Source: Londong [5]

Contamination is generated in different places in the household. Waste disposal from the toilet, the laundry room, the bathroom and the kitchen is carried out uniformly by water. At the moment of wastewater generation these waters are still **separated**. They will be mixed by being discharged through a common sewerage. Water first of all has got a logistic role in this discharging process: it carries off the generated contamination. During this process water - due mainly to diluted matters - becomes used and polluted.

The so called **blackwater** generated in the toilet is heavily charged. Charging is due to the high organic matter content of faeces and urine. Blackwater has got a small proportion in sewage. On the contrary, greywater generated in the bathroom, laundry room and kitchen is low charged and its quantity is significant. Leaving the premises blackwater and greywater is mixed in the sewerage and becomes household sewage.

Stormwater accumulating on the roof is basically not polluted, but - as it is shown in Figure 1-1. - it will become that by mixing when discharged into the sewer.

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5 http://hu.wikipedia.org/wiki

On the way towards the sewage treatment plant industrial wastewater and stormwater from the streets is added to the household sewage. The resulted mixture has been generated by us and then at the sewage treatment plant we concentrate with all endeavours on how to separate the components of the mixture from each other. For this reason one can hear more and more about the separate collection of blackwater and greywater preventing them to mix.

At the time of wastewater generation the minimization of tap water use may be targeted, as well. In this case the once already used and recycled greywater is used for flushing the toilet, which recycling can be implemented in the household. As a consequence the amount of sewage discharged from the household will be less, but it will be more charged as less water carries off the same amount of contamination. Seemingly it is an effective solution subduing the use of tap water. In the sewerage, however, transportation of suspended solid particles can be effective only over a certain flow rate. At low flow rates sewerage sedimentation leads to block that may cause the failure of wastewater disposal. While we need to work toward rational water use we have to admit that a certain amount of water is needed in the sewerage.

Sewerage service consists of two parts: **sewage disposal** and **sewage treatment**. We are talking of sewage disposal, while actually it is the **discharging** of waste generated in the households and the industry **by flushing it with water**. In this process water has got only a logistic role of transportation.

In the sewerage waters of different quality charged to a different extent are mixed. At the sewage treatment plant in course of the treatment process we try to separate the components of this mix. At this point the obligatory question to ask is the following: *Why to mix it if we have to struggle with separation later on?*

Mixing could be prevented by the use of separate sewerages. This idea is not newfangled, but the construction would have a large investment cost. In spite of this the demand for separate collection comes to the view more and more.

It would be difficult to implement separate wastewater disposal or separate collection in a densely populated urban environment, but it might be feasible in a village. Collection of blackwater by vacuum trucks and composting it later on may be profitable. Disposal of greywater could be feasible even in open ditches, but closed pipes are better to the purpose. Sewage treatment at the end of the sewerage system will thus be significantly easier.

Hereinafter let's put an emphasis on **sewage utilization** instead of sewage treatment. This seemingly minor bias, however, leads to the substantive revaluation of a range of things.

2 Reinterpretation of sewage treatment

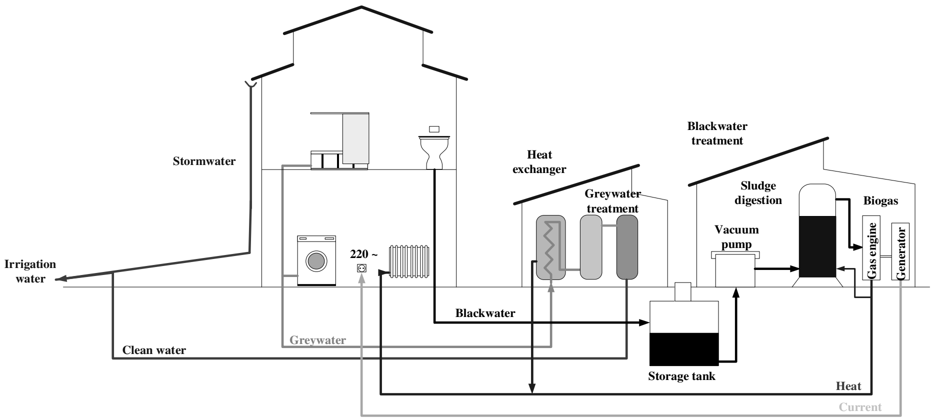
2.1 Sewage utilization in the case of separate collection

Separated sewerage systems have not been developed in the cities because of their large investment costs. Posterior construction of separated sewage collection does not seem to be economical either because there are difficulties in the long distance transportation of blackwater due to large viscosity. Therefore, the establishment of local, complex utilization equipments of small unit performance will gain ground.

Greywater can be utilized in two ways: one is heat recovery, and the other is using it for irrigation water after treatment along with the collected stormwater.

Blackwater contains hardly any water. First biogas is generated by sludge digestion then the gas is combusted in a gas engine. The gas engine needs to be cooled, thus heat energy is generated which can be used for heating. The gas engine powers a generator and the produced current can be reused in the household. Digested sludge will finally be composted. The compost is used as an organic manure.

Today the solution shown in Figure 2-1. still might seem utopistic [5]. However, this form of construction designed for housing estates has one important message as per only hardly polluted greywater needs to be treated in a traditional meaning.



2-1: Local sewage utilization (Source: Londong [5])

Greywater treatment is, however, a much simpler task.

2.2 Sewage utilization in large wastewater treatment plant

Today it is a general fact that a mixture of communal and industrial wastewater enters the wastewater treatment plant through the common sewerage. The amount of wastewater is increased furthermore by added stormwater. There have been many sewage treatment technologies developed. The most common technology is the so called activated sludge technology.

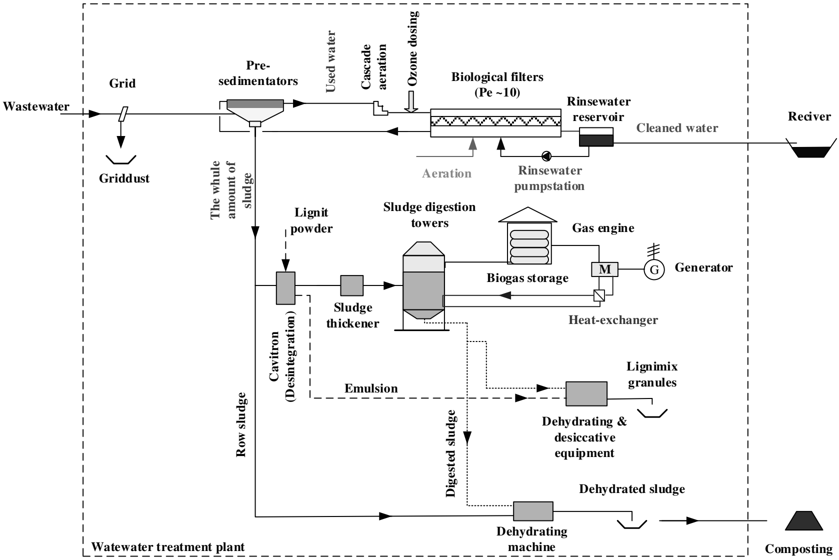
However, the world talks more and more about **sewage utilization** instead of sewage treatment. *Sewage utilization* is not only a fashionable term; it is worth to pay attention to it. The point is that everything what is useful in the wastewater has to be extracted. Consequently, the utilization of the entire amount of sludge separated by (pre)sedimentation should be targeted.

Opinion is divided on whether sludge utilization would be equal to biogas production. Biogas is generated by sludge digestion. It is composed of mainly methane (approx. 60%) and carbon dioxide (approx. 40%). The heating value of a gas with such a composition cannot be compared to that of the natural gas. By the extraction of carbon dioxide and other pollutants - first of all sulphur - the heating value can be improved and thus the possible ways of utilization extend. However, the gas purification process is expensive. Therefore, combustion in gas engines of poor efficiency takes place as a common alternative. Gas engine powers generator which in turn produces current. A part of the generated heat is used for heating the digestion towers. Surplus heat can be used for other purposes. Digested sludge is compostable or may be enriched with lignite.

Figure 2-2. also depicts the case when there is no biogas generation, i.e. the entire amount of raw sludge is composted or stabilized by lignite in course of the LIGNIMIX process [4]. Composting usually takes place off the sewage treatment plant due to its large space demand, while there is enough room to mix sludge with lignite on site.

Either along with biogas production or without that, sludge utilization should anyway serve agricultural purposes, as well. Arable lands badly need organic manure supply. The safety of crop production for food, however, demands that treated sewage sludge applied in the fields shall not contain detrimental substances. This is the reason why an environmentally conscious use of the sewerage system has to be encouraged.

The principle of “polluter pays” is basically right, just the term of polluter has to be revaluated. It is not a polluter who discharges waste of communal origin into the sewerage system, i.e. uses his or her sanitary equipment as it is intended to.



2-2: Sewage utilization in wastewater treatment plant

Treatment of the residual decanted wastewater remains a task. As it has earlier been noted, the today commonest activated sludge technology does not come to mind, as following the separation of the entire amount of sludge the biofilm carrier flocculate is no longer available for us. We need then a process which does not require sludge to be present for the water treatment and an adequate biofilm carrier surface needs to be ensured separately.

Effective treatment of used water can be implemented at low Péclet number. Bank filtration (Pe = 5 - 15) is suitable even for the retention of medicine residues [2]. By using artificial biological filtering of similar parameters unwanted molecules can be extracted from the decanted wastewater, as well. The quality requirements of disposal into natural waters getting stricter and stricter can thus be fulfilled.

3 Mode of action of biological wastewater treatment

As sewage utilization gains ground the basic duty does not change; only it is not wastewater but greywater or decanted wastewater that has to be treated, depending on the formerly shown arrangements. The **theory of biological filtering** leads us to an answer to these tasks without using sludge.

The modelling of bank filtering leads to a general structure [1] that can be considered as the **axiomatic foundation** of the theory of biological filtering. We can state the following:

- A solid surface is needed for biofilm adhesion.
- The treatment process consists of three consecutive processes. Convective flow or leakage conveys pollutant to the biofilm. Conductive flow or diffusion detaches pollutant from the main flow and ingests it into the biofilm. Logistic stages based on the principles of flow technology are preconditions to the processes taking place within the biofilm.
- Nutrient decomposition takes place within the biofilm.

3-1: Consecutive elements of biological filtering and feedback

	Sub-process	Condition (driving force)	Maintened by	
	Convective material flow, persolation	Pressure difference	Pumping, mixing	
Serial process ↓	Conduktive material flow, diffusion	Concentration difference	Bacteria's work	Feedback
	Biochemical process, Nutrient decomposition	Solid surface for biofilm adhesion, Redox envinronment	Bacteria's instict	

Table 3-1. shows the momentum of each sub-processes as well as the way how to maintain them. Leakage occurs in the deposit to the effect of pressure difference which is maintained by pumping or mixing. Diffusion is driven by the concentration difference.

Nutrient decomposition is a biochemical action which converts the molecule entering the biofilm thus “eliminating” its concentration within the biofilm. Concentration difference outside of and within the biofilm is thus **continuously reproduced.**

Diffusive motion comes off uniformly in all directions of space such as it can be observed in the case of Brownian motion. Ions move also according to the principle of diffusion. By the aid of an electric field, however, the charged particles can be diverted into one direction. In order to differentiate it from spontaneous diffusion this directed motion is called **drift**. In our case a one-way diffusive motion from the water towards the biofilm can be observed. The momentum is provided by a **continuously reproduced concentration difference** due to the bacteria’s activity.

In Table 3-1. the **life instinct** of bacteria means the force that induces them to decompose nutrients. In terms of systems engineering decomposition induces a feedback by the reproduction of a concentration difference.

3.1 Logistic criteria of biological filtering

Efficiency of nutrient decomposition in logistic terms is also determined by the size of the surface that can be colonized by bacteria. To decompose a large amount of nutrients a large number of bacteria is needed which, in turn, are able to adhere only to a large surface. The larger the surface size in a given volume is the smaller the size of the biofilm carrier particles are.

The logistic criteria of biological filtering are characterized by the Péclet number as follows:

$$\mathbf{Pe} = \frac{\mathbf{w\, d_m}}{\mathbf{D_S}}$$

where **w** [m/s] is the filtering rate
d_m [m] is the standard particle diameter (in the case of sand filter it is equal to the typical particle diameter)
D_s [m^2/s] is the diffusion factor of substrate (the decomposable pollutant)

The Péclet number is a dimensionless number. It includes three different characteristics: the most important parameter of operation, i.e. filtering rate (w), the quality of water to be treated characterized by the diffusion factor of the pollutant (D_s), and the specific characteristic of the filtering substrate or the biofilm carrier deposit, i.e. the particle diameter (d_m), which refers to the size of the carrier surface.

The Péclet number is originally interpreted as the ratio of convective and conductive currents.

$$\mathbf{Pe} = \frac{\mathbf{w}}{\frac{\mathbf{D_S}}{\mathbf{d_m}}} = \frac{\textit{convective velocity}}{\textit{conductive velocity}}$$

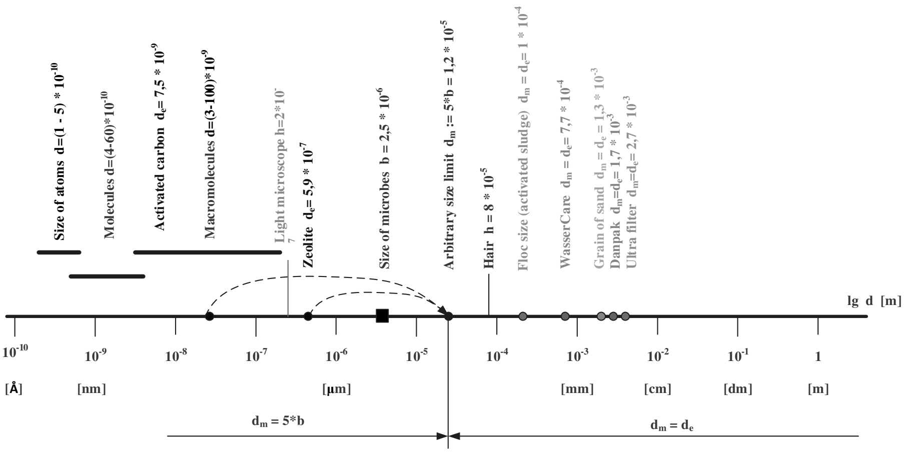
The precondition of effective decomposition in this approach is that the nutrient that arrives to the biofilm is able to penetrate into it, i.e. the desired value is **Pe ~ 1.**

There is another, more illustrative interpretation. After an algebraical conversion of the fraction we get the following form:

$$\mathbf{Pe} = \frac{\dfrac{\mathbf{d_m^2}}{\mathbf{D_s}}}{\dfrac{\mathbf{d_m}}{\mathbf{w}}} = \frac{\boldsymbol{\tau}}{\mathbf{t}} = \frac{\textit{diffusion time}}{\textit{retention time}} \quad \left(= \frac{\mathbf{d_m^2}}{\mathbf{D_s}} \frac{\mathbf{w}}{\mathbf{d_m}} = \frac{\mathbf{w\,d_m}}{\mathbf{D_s}} \right)$$

The result is the ratio of the time needed to take the d_m long diffusion way and the retention time spent in front of the d_m sized biofilm carrier particle.
The precondition of effective decomposition is when these two periods of time are nearly equal to each other (Pe ~ 1). When Pe<1 then no sufficient amount of nutrient arrives to the biofilm, while when Pe>>1 then the nutrient passes away quickly in front of the biofilm instead of getting ingested.

The calculation of the Péclet number seems to be easy. However, in the case of different sewage treatment processes there are significant difficulties in the interpretation and determination of the given factors. Some geometric considerations may be necessary in order to determine the equivalent d_e and the standard d_m particle diameters [1].



3-2: Equal and standard particle diameters

Based on the equal and standard particle diameters the biofilm carrier substrates can be lined up. The applied logarithmic scale indicates that there is a large distance between the sizes representing some of the filtering substrates. It can be seen that the plastic biofilm carrier products (WasserCare, Danpak) available in the market at the present still lag behind the demands, and their specific surface is rather small. Bacteria are not able to fully colonize the large specific surface of activated carbon and zeolite due to the bigger size of those.

3.2 Kinetics of biochemical processes

3.2.1 Metabolism of cells

Nutrient decomposition within the biofilm - if we only state that it has happened - seems to be simple. If we have a closer look at it, we get a more diverse picture. It is worth to recall briefly the activity mechanism that has already been justified by biologists for a long time in order to better understand systems engineering relations.

The metabolism of cells can be described by the Michaelis-Menten enzyme kinetics (Table 3-3/A). As a solution of a differential equation system we get a relation referring to the reaction rate - the rate of product generation - depending on the substrate content (Table 3-3/B). The model is simple and provides a good phenomenological description of the phenomenon. Parameters v_{max} and K_m are easy to measure.

3-3: Enzyme kinetics

A The differential question system

$$\mathbf{E+S \underset{k_{-1}}{\overset{k_1}{\longleftrightarrow}} ES \xrightarrow{k_2} P+E}$$

E	**enzyme**
S	**substrate**
ES	**complex**
P	**product**

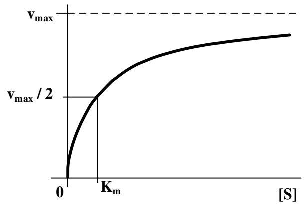
$$\frac{d[\mathrm{ES}]}{dt} = k_1[\mathrm{E}][\mathrm{S}] - (k_{-1}+k_2)[\mathrm{ES}] = 0$$

$$[\mathrm{E}]+[\mathrm{ES}]=[\mathrm{E}]_0$$

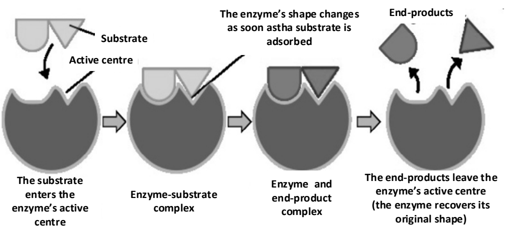
$$[\mathrm{ES}] = \frac{[\mathrm{E}]_0[\mathrm{S}]}{[\mathrm{S}]+\left(\frac{k_{-1}+k_2}{k_1}\right)}, \quad \frac{k_{-1}+k_2}{k_1} = K_m$$

$$\frac{d[\mathrm{P}]}{dt} = k_2[\mathrm{ES}] = \frac{k_2[\mathrm{E}]_0[\mathrm{S}]}{[\mathrm{S}]+K_m} = \frac{v_{\max}[\mathrm{S}]}{[\mathrm{S}]+K_m}$$

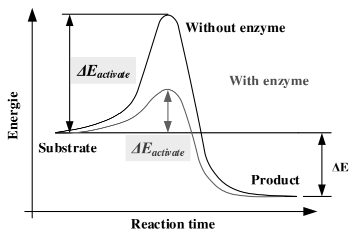
B The result



C Pitching the patterns



D Reduce the activate energy



The theory elaborated at the beginning of the 19th century justified the role of enzymes in the process illustrating the mechanism of molecule decomposition by geometric structures. A given enzyme is able to decompose only a given type of substrate. This is indicated by the “key fitting the lock” geometric forms in the figure. In order decomposition would be accomplished the given enzyme has to be present in the space (Table 3-3/C).

Similarly to every living organism cells also need energy to sustain their vital processes. They gain this energy from the decomposition of the substrate. Energy released in course of the exothermic process ensures cell activity. Enzymes take part in this process as catalytic agent. To their effect the activation energy needed for the decomposition will be significantly less (Table 3-3/D).

From our biological studies we may know that decomposition takes place in more than one step. This type of multistep process is the consecutive stages of nitrification and denitrification. The product generated in the first reaction becomes a substrate in the next stage. Gradual decomposition may have the risk of getting the process stucked somewhere, not being completed and leaving behind undesired, maybe even toxic matters in the water.

In practice decomposition processes used to be described by stoichiometric equations. The end-product is mostly water and carbon dioxide which may be apostrophized as that of an oxidative burning process. Energy released in course of the reaction, however is not typically heat energy as it is general at burnings with flame - but chemical energy from which the cell gains energy needed for its activity and life subsistence. Gaining energy necessary for life subsistence may be considered as life instinct.

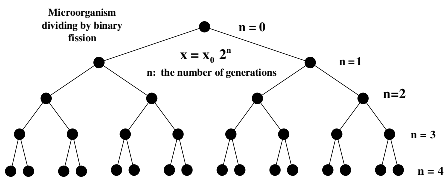
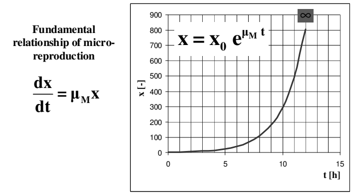
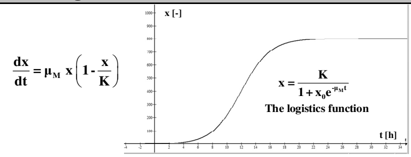
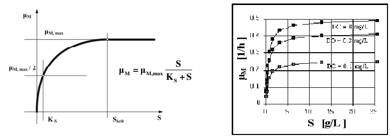
Mechanical screening retains pollution while biological filtering “burns” it. Mechanical screens needs to be regularly cleaned. On the contrary, biological filters are self cleaning.

3.2.2 Microbial reproduction

Bacteria are single-celled organisms. Their body builds up of protein, nucleic acid, lipids and water. A significant part of the protein content is enzyme protein.

Bacteria, such as all other living organisms, have an important characteristic: namely that they are able to reproduce. The most frequent form of reproduction is reproduction by fission. To the analogue of the Michaelis-Menten enzyme kinetics, the kinetics of microbial reproduction was developed by Monod some fifty years later in 1949.

3-4: Kinetics of microbial reproduction

A Binary fission	B Reproduction of relative growth
	
C The logistics function	D The Monod coefficient
	

Exponential growth $x_0=2$, $\mu_M=0,5$

K=800 $x_0=399$, $\mu_M=0,5$

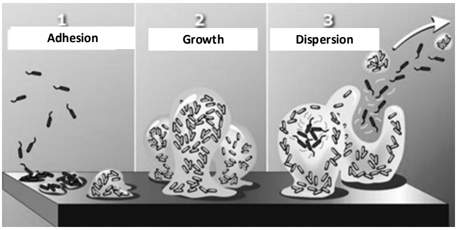
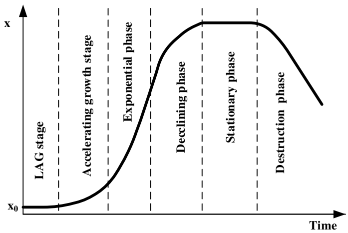
Binary fission (Table 3-4/A) can be described by a differential equation, as well. The constant is a coefficient characteristic to a reproduction of relative growth μ_M, which shows the increase rate of subsequent generations. The solution of the differential equation results in an exponential function. The function keeps to the infinite as time increases (Table 3-4/B). In the case of closed systems a finite growth is realistic. The solution of the corrected - “slowed down” in growth - differential equation will be the so called logistic function (Table 3-4/C).

The μ_M size of the exponent can be determined by measurement. Its value, depending on the substrate content, shows saturation characteristic. Similarity can be detected then in the development of the reaction rate of the Michaelis-Menten kinetics and the substrate dependence of the Monod kinetics exponent. The upward rise of the curves can be characterized by the provision of **semisaturation constants** (K_m, K_s).

The growth rate of microbes is of the order of an hour. Although the saturation value $\mu_{M,max}$ becomes larger along with the increase of dissolved oxygen content in the water the growth rate depending on the substrate content - the rise of the saturation curve - does not substantially change. (Table 3-4/D). The rise of the saturation curve is determined by the type of the substrate and the reproducing bacteria species, respectively.

Biofilm is not a timely static formation; it has dynamics.

3-5: Reproduction and mortality

A Adhesion – Growth - Dispersion	B The growth in time
	

Growth stages are distinguished. Accelerating growth stage, then declining and stationary phases are followed by the death phase. Death can be related with dispersion (see Table 3-5/A and B).

The reproduction or growth stage can also be described with the help of the logistic function (Table 3-4/C). For this x_0, K and μ_M parameters have to be selected and marked off.

3.3 Theory of biological filtering

Biological filtering is a complicated biochemical process where nutrient decomposition depends on several variables. The function relation between variables was defined by using dimension analysis [1]. The mathematics- and physics-based process starts with listing the substantive variables. In the first step we reduce the number of variables by generating dimensionless figures. In the case of the model is derived for bank filtration we get six dimensionless figures, from among which Péclet number and L/d geometric ratio have a substantial role (Table 3-6/A). These can be changed substantially by the

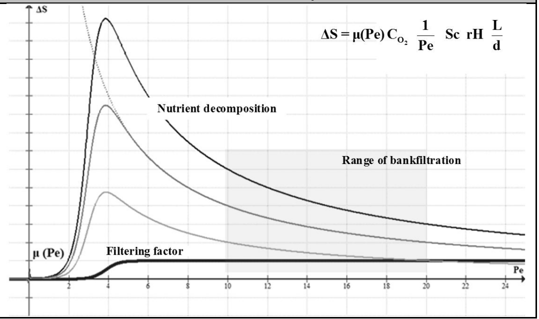
The methodology of dimension analysis makes it possible to interpret the function relation describing the phenomena, as well. According to the formula that can be described by heuristic means (Table 3-6/B) nutrient decomposition is inversely proportional with the Péclet number and is directly proportional with the L/d_m ratio.

Illustrating the resulted formula as a function of the Péclet number - depending on the size of the other factors - we get a host of hyperbola. In the range of very low Péclet number the grade of nutrient decomposition with a constant filtering factor would be infinite, which is impossible.

3-6: The relations of nutrient decomposition

A The dimensionless numbers	
$\Pi_1 = \Delta S / C_{O2}$	Ratio of concentrations
$\Pi_2 = \nu / D_S$	Sc-number (Schmidt)
$\mathbf{\Pi_3 = w\, d / D_S}$	**Pe-number (Peclet)**
$\Pi_4 = D_{O2} / D_S$	Ratio of diffusion coefficients
$\Pi_5 = E_h\, F / RT$	Ne-coefficient (Nernst)
$\mathbf{\Pi_6 = L / d}$	**Geometric ratio**

B The result of dimensionanalysis



Assuming the existence of $\mu = \mu(Pe)$ function relation the unbounded growth of hyperbolas is reversible. Starting off from the two-grade materialization of biofilm nutrient supply - nutrient transport to the biofilm then its ingestion into the biofilm - let us identify formally the filtering factor with the logistic function of microbial reproduction (table 3-4/C), namely let it be

$$\mu := \mu(Pe) := \frac{\beta}{1 + a\, e^{-b\, Pe}}$$

where

β is the proportional part of the filtering factor, the size of which can be determined by measurement, and where

by the correct selection of a and b parameters near the value of Pe = 1 the maximum value of the function, while at Pe = 0 the nearly 0 function value can be reached. (By selecting the values of a=100 000 and b=12 - according to our expectations - the infinite characteristic of hyperbolas will disappear, the maximum value of the function will be near 1 and the nutrient decomposition curve will intersect the y-axis near the pole (Table 3-6/B).

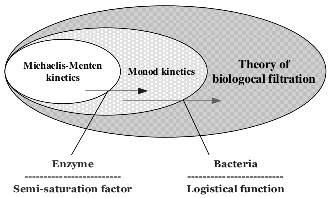
Having provided the filtering factor the theory of biological filtering has been completed.

Summarizing our foregoing results we can state that theories build on each other. Figure 3-7 summarizes this.

The result of the Michaelis-Menten kinetics has inspired Monod when he was interpreting the relations of microbial reproduction. For the description of reaction rate on the one hand, and that of the relative growth rate on the other hand, functions of the same shape are used. At both kinetics it is the enzyme that embodies the conceptual similarity.

The microbial reproduction equation of the Monod kinetics carried out in a closed space, the so called logistic function has lent its shape to the filtering factor of the nutrient decomposition model. Setting a colony of bacteria reproducing according to the principles of Monod kinetics and supplying them with nutrients is the task of the process based on the theory of biological filtering.

A Boxes in box



B Characteristics of the theorys

Theory	What is it about?	The place of occurrence	Key parameter
Michaelis-Menten kinetics	Metabolism of cells	Cell	Reaction rate
Monod kinetics	Microbial reproduction	Biofilm	Relative growth factor
Theory of biological filtering	Biological filtering	Biological reactor	Filtering factor

3-7: Interconnecting processes

Through these steps can we get from the cells through the microbes to the events ruled by the theory of biological filtering and finally to the clearing of water.

4 Summary

Sewage utilization can be maximized if the total amount of sludge is disposed, as it is recommended by the CARISMO process, as well [3]. This may be feasible, however, only if the decanted wastewater can be treated without the involvement of sludge flocs. It is also required that medicine residues shall be filtered already in the sewage treatment plant. By a more effective treatment of decanted wastewater environmental aspects may better prevail. Jekel-experiments [2] and the theory of biological filtering drafted here lay the foundation of all this and make this possible.

Capacities will be fully exploited when the digested sludge is applied to arable land as it is shown in Figure 2-2. in alternative forms.

This integrated approach, in addition to minimizing environmental pollution, can also provide us with a source of energy. Sewage sludge utilized in arable land is not only manure for plants but by improving the water retention ability of the soil it also helps to diminish the extreme manifestations of climate change.

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Multi Criteria Analysis for Wastewater Management in practical applications

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Abstract

Multi Criteria Analysis (MCA) is a structured approach to determine the overall preference among alternatives, where the alternatives accomplish several objectives. The advantage of the MCA processes is that it enables an integrated assessment of subjective and objective information with stakeholders’ values in a single framework. This study presents two different real case studies for wastewater management solved by different techniques of MCA; the first MCA technique is using the overlay weighted model by using the ArcGIS tools and compared with Boolean Logic to determine the best locations for the infiltration ponds which will use the effluents of the treated wastewater plants (45,000 m^3/d and 150,000 m^3/d in 2025) of a new industrial city in the western desert in Egypt in the purpose of recharging the groundwater to restore the rapid rate of groundwater level depletion due to the unmanaged overexploitation and to store the wastewater under the ground instead of polluting other water bodies or being lost by evaporation. This stored water can be re-pumped and reused after certain time and distance, hence reused for agriculture or municipal purposes. The MCA using the weighted model could give more accurate suitability map while Boolean logic suggested wider ranges of areas. The another application was to evaluate the best scenarios for improving the water quality of a 56 Km reach of the Nile River which receives several effluents of wastewater from different sources (drains, factories and water treatment plants). For this purpose the reach has been calibrated and simulated using Mike 11- ECO lab, to test and evaluate the different scenarios for improving the water quality of that reach. Also, this reach has been evaluated by the Analytical Hierarchy Process (AHP) for different MCA parameters and indicators. The MCA tools showed very good results in evaluating and judging the best management scenarios in each application.

Keywords: Multi criteria Analysis (MCA), Wastewater Management, Overlay weighted Model, ArcGIS, Boolean Logic, Groundwater Recharge, Analytical Hierarchy Process (AHP), River Reach, Water Quality, Mike 11

1 Introduction

Multi Criteria Analysis (MCA) is a process of integrated assessment of projects, alternatives or options for ranking or selecting, priority setting among the finite set of projects, alternatives or options. MCA is a structured approach to determine overall preference among alternatives, where the alternatives accomplish several objectives. The advantage of the MCA processes is that it enables an integrated assessment of subjective and objective information with stakeholders' values in a single framework.

Different MCA or Multi-Criteria Decision Making (MCDM) methods have been widely used in the area of environmental resources planning and management. Recio et al. (1999) developed a system for water evaluation and monitoring that was applied to an aquifer in Spain. Raju et al. (2000) used MCDM analysis for a case study of an irrigation area to rank different alternatives using economic, environmental and social factors as criteria. Of all the MCDM tools, Analytical Hierarchy Process (AHP) is being used widely because of the nature of the problem and the structure of the relevant criteria (Karamouz et al., 2002).

2 Application 1: MCA using ArcGIS Maps

Applications of remote sensing (RS) and GIS in site selection for artificial recharge and flood spreading management have been the topic of several researches (Chopra and Sharma, 1993; Saraf & Choudhury, 1998; Mehrvarz & Kalantari, 2007; Alesheikh et al., 2008; Balachandar, 2010, Zehtabian, 2001). The success of artificial groundwater recharge via surface infiltration is discussed by Fennemore et al. (2001), Haimerl (2001) and Bouwer (2002). Each artificial recharge technique has its own characteristics and the method of site determination (Ghayoumian et al., 2007). In the present study the direct surface techniques by recharge ponds are suggested, as the soil of the study area has a good permeability and the area of implementation is wide enough. The advantage of these direct-surface techniques lies in the ability to increase the groundwater potential and the added benefit from the filtering effect of soils and the transmission of water through the aquifer (Asano, 1985). The main objective here is finding out the best locations for artificial recharge of groundwater in a semi-arid area to provide it with a new source of water by making use of the huge amounts (150,000m^3/d) of the misused treated waste water. For this purpose so intensive data have been collected to carry out this study like satellite images, maps, reports, soil characteristics and hydrological data. All of these data have been stored and manipulated by using ArcGIS, hence two approaches, overlay weighted model and Boolean logic, were applied to carry out the study analysis and to hold on a comparison between the two approaches results and their efficiencies.

2.1 The Study Area

The study area is Sadat City which is located between 30° 21´ E and 30° 41´ E longitude and 30° 19´ N and 30° 34´ N Latitude and it lies at the kilometer 93 on Cairo – Alexandria highway north-west of Cairo in Egypt, its total area is 523.5 km^2, **Figure 1.** Sadat City is a relatively new industrial city in the western desert and west to the Nile Delta in Egypt. This city is based upon the industrial and agricultural activities. Its unique location between Cairo (The capital) and Alexandria, along the Delta, has made it a big centre to attract the local and foreign investments to form a large urban community. The total inhabitant area is 18 km^2, this area is divided into 12 parts with about 100,000 persons and it includes 5 industrial areas. The city is surrounded by a green area of 126 km^2.

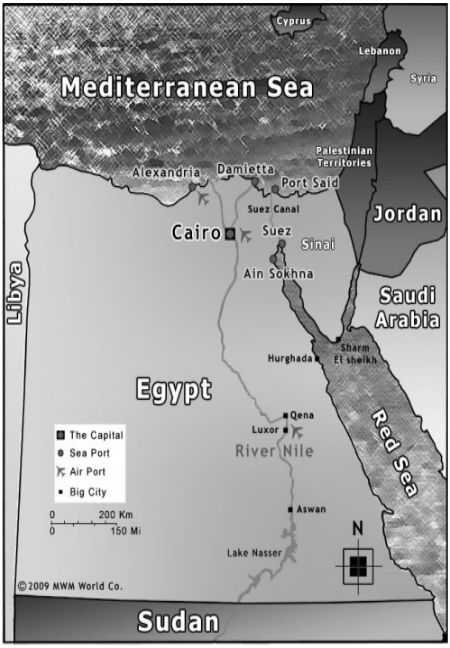

Figure 1: The study Area location

Figure 2 shows the Land use and the groundwater flow directions from the north east into the south west. All the city activities are mainly depending on the groundwater; most of the production (supplying) wells were constructed near to the residential parts of the city to cover the city needs for water, in addition to some other private wells which are used for irrigation purposes. The city treatment plants are existed in the north east of the city and it applies tertiary treatment for the industrial and municipal waste water.

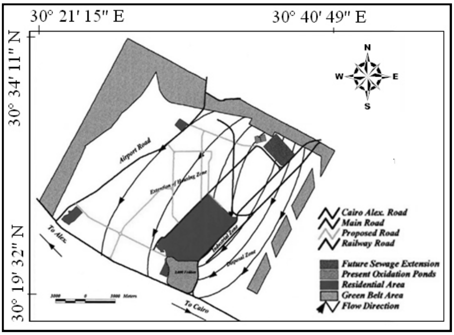

Figure 2: The study area land use

2.2 Weighted overlay suitability model

To meet a specific objective, it is frequently the case that several criteria will need to be evaluated. Such a procedure is called Multi-Criteria Evaluation (Carver, 1991). A "Weighted Suitability Model" is developed using GIS techniques for proposing locations suitable for applying groundwater recharge depending on a number of thematic layers and based on the principle of Multi-Criteria Evaluation. Such models are used for applying a common measurement scale of values to diverse and dissimilar inputs in order to create an integrated analysis. Additionally, the factors of the analysis may not be equally important. Each individual raster cell is reclassified into units of suitability and multiplied by a weight to assign relative importance to each and finally add them together for the final weight to obtain a suitability value for every location on the map; this can be interpreted by Eq.1 (Eastman, 2001).

$$S = \Sigma\, w_i\, x_i \qquad (1)$$

where,

w_i = The weight of i factor map

x_i = Criteria score of class of factor i

S = Suitability index for each pixel in the map

In this study, all the thematic layers were integrated in ArcGIS 9.3 platform in order to prepare a map depicting suitable areas for artificial groundwater recharge. The total weights of each pixel of the final integrated layer were derived from the following equation;

$$S = (SLf\ SLc + LUf\ LUc + LWf\ LWc + LTf\ LTc + LRf\ LRc + L\ f\ Lc + PRf\ PRc + DGf\ DGc \qquad (2)$$

where, SL is Land slope, LU is distance to the residential (urban) areas, LW is the distance to the supply wells, LT is the distance to the treatment plants, LR is the distance to the roads, L is the land use, PR is the pollution risk and DG is depth to groundwater. The subscript letter ‘f’ represents the weight of each factor, while ‘c’ represents the weight of each class of the individual factor. Thus the artificial groundwater recharge index ‘S’, which is dimensionless quantity that helps in indexing the probable ground water recharge zones in the area, was estimated using Eq. (2) for each pixel in the final integration layer and was regrouped into different classes with equal class interval to divide the entire study area into different artificial recharge zones (Chowdhury et al., 2006).

2.2.1 The conceptual model

In this study, the main thematic layers are generated as an input for selecting suitable sites for a recharge project. A number of processes were performed to prepare these layers for being used as an input in an overlay weighted model. The following sections are going through the main steps which have been done.

To model the spatial problem a diagram of the objectives, process models, and input datasets was created to reach the study goals was drawn, **Figure 3**.

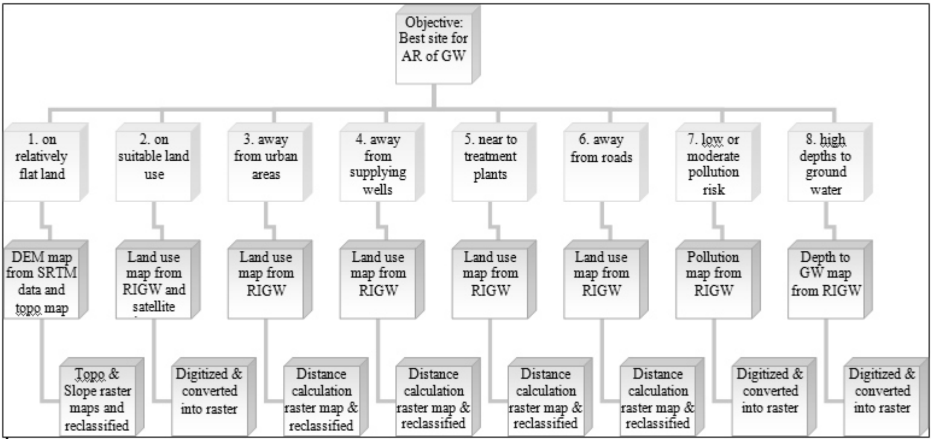

Figure 3: The work plan for the needed data and the main steps

AR: Artificial Recharge; GW: Groundwater; RIGW: Research Institute of Groundwater

2.2.2 Thematic Layers for ArcGIS Analysis

After adding the DEM and its data to ArcGIS platform the topographic and the slope maps could be generated by the use of the spatial analyst tools, then the study area was clipped according to its known coordinates. Three maps (land use, pollution risk and depth to groundwater) for the city were obtained from previous researches which have been done by the Research Institute of Groundwater in Egypt (RIGW, 2006) and they were added to ArcGIS and georeferenced with the first reference map (from the DEM), then they have been digitized and converted into raster maps. **Figure 4** shows the digitized pollution risk map as an example.

2.2.3 Reclassifying the distances maps

All the distances maps (distances to roads, urban areas, production wells and treatment plants) have been reclassified to integer values instead of ranges to be used as inputs in the weighted model. To reclassify these maps the reclassify function was applied. A value of 10 was assigned to the most suitable range and 1 to the least suitable range. All the layers have the same range of classes (1 to 10). **Figure 5** shows an example for the reclassified map of distances to roads.

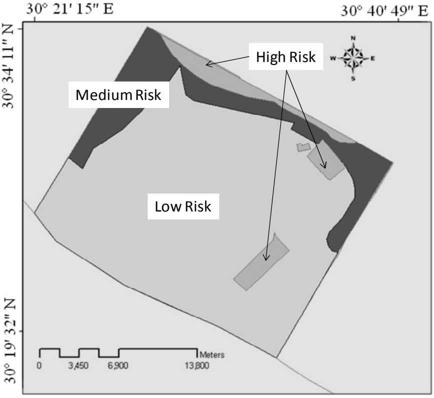

Figure 4: Pollution risk map on ArcGIS

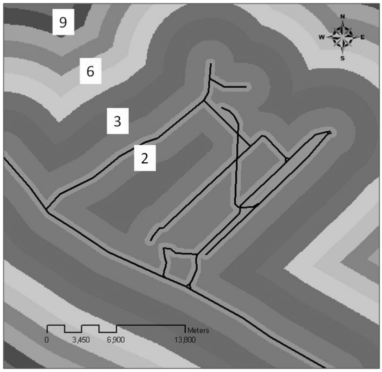

Figure 5: Reclassified distance to roads

2.2.4 Weighted Indexing table

Each raster is assigned a percentage influence according to its importance. The weight is a relative percentage, and the sum of the % influence weights must add up to 100. Each cell value is multiplied by their percentage influence then added to create the output raster. A weighted indexing table has been adopted to suggest the ideal location for artificial recharge using the eight parameters, as shown in **Table 1**. The weights in the present study were given upon the experience of other specialists from previous studies and upon the economic point of view (Elbeih, 2007), so in this study all the affecting factors were given an equal weight = 10 % except only the distance to treatment plant and the land use which were given weights equal to 20 %, because it is expected that the source of the water for the artificial recharge of groundwater in this city will be provided from the treated waste water from the treatment plants, so it is preferable and costly effective if these recharge areas are close to the treatment plants, moreover it is preferable to have these projects in bare lands more than agricultural areas or others not to affect the going on investments.

Table 1: The weighted indexing table

No.	Input Raster	Field	category	class	Influence (weight) %
1	Slope	Very steep	Very Poor	1	10
		Flat	Excellent	10	
2	Dist. to Urban	Very close	Very Poor	1	10
		Farthest	Excellent	10	
3	Dist. to suplying wells	Very close	Very Poor	1	10
		Farthest	Excellent	10	
4	Dist. to Treatment Plants	Farthest	Very Poor	1	20
		Very close	Excellent	10	
5	Dist. to Roads	Very close	Very Poor	1	10
		Farthest	Excellent	10	
6	Landuse	Green Area	Very Poor	1	20
		Residents	Poor	2	
		Industries	good	3	
		Treatment	Very good	6	
		Bare	Excellent	10	
7	Pollution Risk	High	Very Poor	1	10
		Medium	Poor	6	
		Low	Excellent	10	
8	Depth to GW	Less than 15 m	Very Poor	1	10
		15 to 25 m	Poor	6	
		25 to 40 m	Very good	8	
		Larger than 40 m	Excellent	10	

2.2.5 Suitable recharge locations

After preparing all the thematic layers and the table of weights, the weighted model could be built and run on ArcGIS. This came up with the most favorable sites selected using the previously mentioned criteria as shown in **Figure 6.** The final integrated layer was classified from excellent to not suitable based on the weights assigned to each criterion. Weight “10” represents excellent sites while weight “0” represents unsuitable sites or areas out of the research study. It can be observed that the most suitable zones for artificial recharge lie in bare lands, away from the urban areas and near to the treatment plants.

2.3 BOOLEAN LOGIC METHOD

Boolean logic is an alternative way to find suitable locations for artificial recharge (rather than creating a suitability map) to query the required data. Once all the needed datasets (the thematic layers) have been created, such a query would be to find all the suitable locations. Probably the simplest and best-known type of GIS model is based on Boolean operations. Robinov (1989) introduced the use of Boolean operations for reasoning with geological maps. In effect, Boolean modeling involves the logical combination of binary maps resulting from the application of conditional operators (Bonham Carter, 1996). Only one or zero values are assigned to each unit area, specifying whether it is satisfactory or unsatisfactory, respectively. The Boolean model consists of AND and OR operators. Based on set theory, the AND operator yields the logical intersection of the two data sets, and the OR operator obtains the logical union of the two data sets. The query data is analyzed based on Boolean logic and entered in the Raster Calculator (from spatial analyst) according to the existing thematic layers as following:

[Slope output] < 5 Degrees & [Distances to Urban Areas] > 2000 m & [Distance to wells] > 3000 m & [Distances to Treatment] < 10000 m & [Distances to Roads] > 500 m & [Depth to GW] > 15 m & [Landuse] == The bare land & ([Pollution_Risk] == low | [Pollution_Risk] == medium)

== means equal, | means OR, & means AND

The result is a Boolean true or false map for the locations that meet or do not meet the given criteria. The result of the Boolean query for identifying suitable locations for the artificial recharge site is shown in **Figure 7**. Areas in green are not suitable and areas in violet are suitable. Comparing weighted models with Boolean models, it is identified that weighted models has more flexibility and ability for priority indication on spatial units of factor maps.

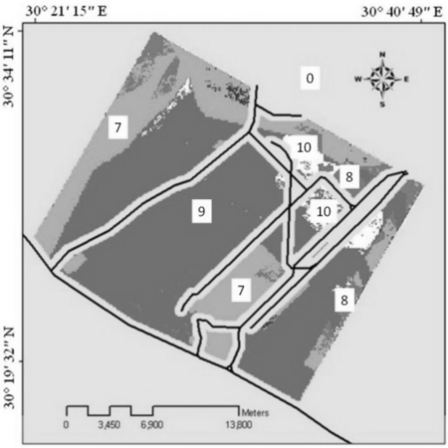

Figure 6: The suitability map from the weighted model by ArcGIS

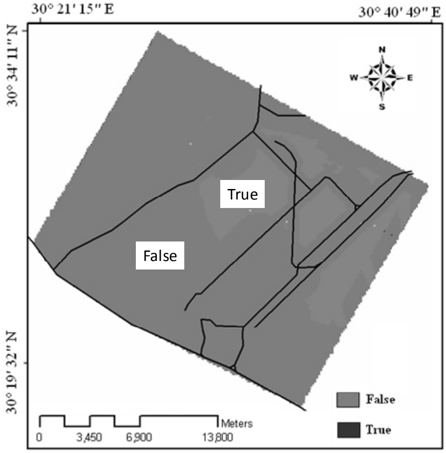

Figure 7: Boolean True-false map

3 Application 2: MCA using the Analytical Hierarchy Process

3.1 Study Area

The study area covers Cairo governorate along the River Nile, extended from El Saff town at Km 877.00 in the South to El Kanater town at Km 953.00 in the North. Cairo is located on the Nile River about 160 kilometers south of the Mediterranean Sea. Cairo has an area of 353 km^2 with an average reach length along the river about 50 km (from Km 900 to km 950 Referenced to Aswan High Dam).

The measured data include 48 locations including 4 locations for drains, 3 locations for industrial pollution sources and 7 locations for waste water from drinking water plants (DWPs) sludge disposal. The collection and various chemical analyses for water quality parameter are done at Cairo Drinking water Company Central Laboratory. Figure (8) illustrates sample sites.

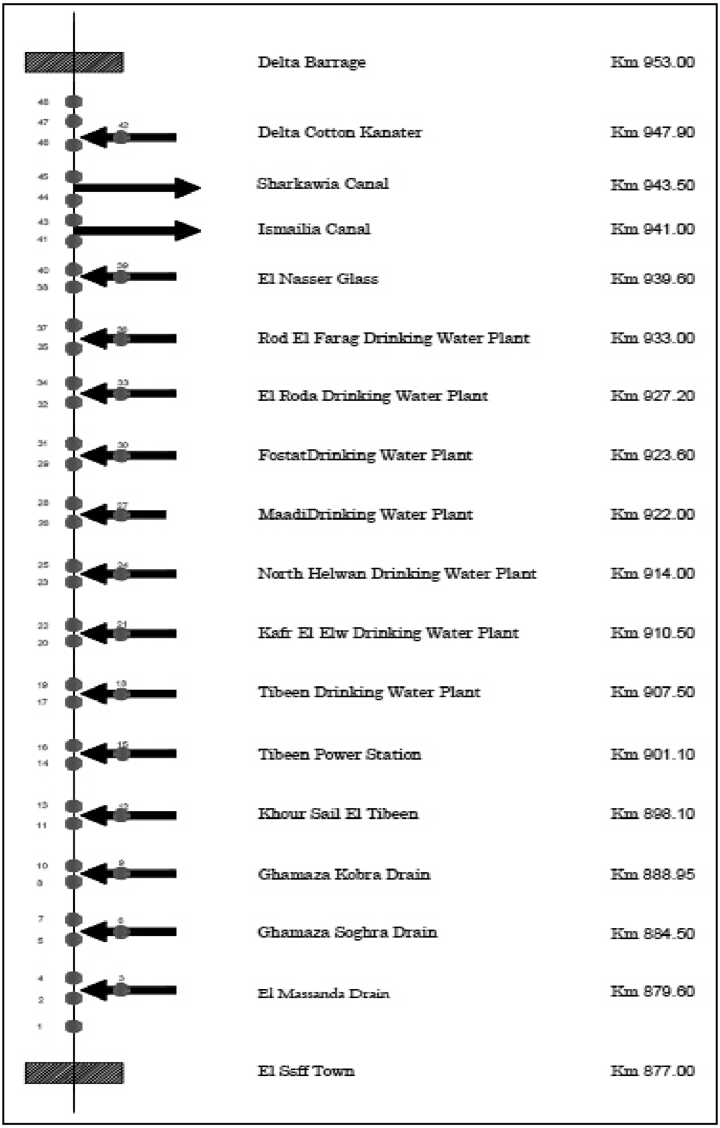

Figure 8: The wastewater outfalls on the river reach

3.2 MIKE 11 Calibration

MIKE11 model was calibrated using water quality data set collected during 2012. Salinity was chosen for calibration process because it is considered a conservative material and it is an excellent water mass tracer.

3.3 MIKE 11 Models

After calibration of MIKE11 model, the model was successfully executed as described in last sections. The input dataset used for this model run is water quality data for year 2013. The Hydrodynamic Module (HD), Advection-Dispersion Module (AD) and Ecological Laboratory Module (ECO Lab) were used for the Purpose of simulation in this research. In MIKE 11 environment some of the models that can be selected are dependent on other modules in a simulation and it is therefore required to have more modules selected (e.g., Selection of ECO Lab, which will form the basis of the water quality simulation selects AD-model and HD model also). Therefore for performing the water quality model, HD model and AD model were run. Water Quality modeling takes place through the ECO Lab model entry where DO, BOD, COD and FC as water quality parameters were selected from the ECO Lab templates.

3.4 Water Quality Management Scenarios

Water quality management scenarios are simulated using 2013 WQ data set and the pre-calibrated model as a base condition. The main objective of this simulation is to propose alternative solution to improve the water quality of the study reach; however seven scenarios using Mike11 HD, AD and EcoLab modules are designated as explained in Table (2), after Reda et. al. 2015.

Table 2: Management Scenarios Description

Scenario	Description
Base Condition	**Pre-Simulated model with 2013water quality dataset.**
Scenario (1)	**Treatment of four polluted drains (El Massanda, Ghamaza Soghra, Ghamaza Kobra and Khour Sail drains) using wetland technique in order to reduce pollution loads from these drains.**
Scenario (2)	**Stopping the sludge disposal effluent from the treatment processes of seven DWPs (Tibeen, Kafr El Elw, North Helwan, Maadi, Fostat, El Roda and Rod El Farag) and applying sludge treatment alternative.**
Scenario (3)	**Twenty percent increase in study reach discharge over the maximum discharge in low demand period in order to dilute the effect of pollution concentrations.**
Scenario (4)	**Increase the drains discharge by twenty percent.**
Scenario (5)	**Combination of scenario (1), scenario (2) and scenario (3).**
Scenario (6)	**Treatment of four polluted drains by construction wastewater treatment plants to reduce pollution loads from these drains.**
Scenario (7)	**Combination of scenario (1), scenario (2) and scenario (6).**

3.5 MCA Framework

MCDA identifies multiple criteria against which the study area water quality management scenarios can be evaluated and then compared to each other. MCA technique mainly based on ranking for prioritizing the alternatives through technical, economical environmental and socio-cultural criteria (Belton, 2002), Figure (9) shows the main MCA Criteria and Indicators.

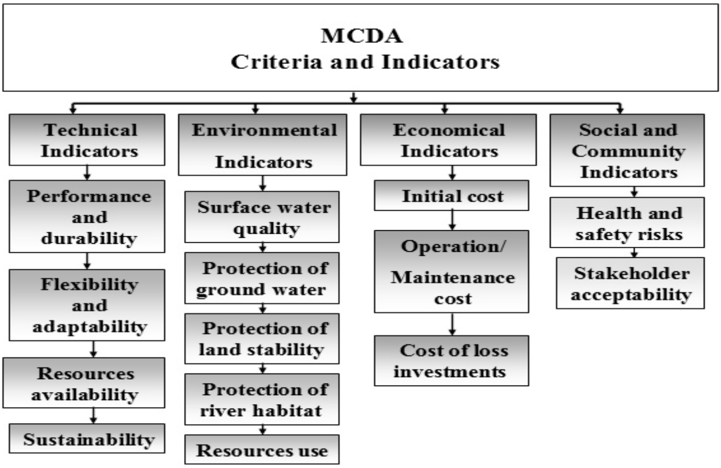

Figure 9: MCDA Main Criteria and Indicators (*Rosén et al. 2009)*

The following methodological steps were followed to construct MCA, Howard (1991):-

- Determine available management scenarios "Discrete decision options" which usually will be ranked or scored.
- Choose evaluation criteria. The criteria are used to measure the performance of decision options. They should be non-redundant and relevant to the decision making objectives. Redundant criteria are typically highly correlated and measure the same underlying factor.
- Obtain performance measures for the evaluation. These values can be sourced from expert judgments and other environmental models.
- Weight the criteria based on the degree of importance of each adaptation option.
- Rank or score the options. At this stage the weights are combined with the performance measures to attain an overall performance rank or score for each decision option.
- Prioritization of options based on the final weighted scores per option which calculated according to the equation:-
- $Value(x) = \sum_{i=1}^{n} W_i(x) \times C_i(x)$

Where:-

Value (x) = Final value for alternative x

Wi (x) = Weight of criterion i for alternative x

Ci(x) = Score of criterion i for alternative x

3.6 MCA Results

Table (3) provides a semi-quantitative (but nevertheless still subjective) according to MCA evaluation approach. MCA scoring system is based on the procedure developed by the US Environmental Protection Agency (Heaney et al., 1997) which scores all positive aspects of each system type from 1 (lowest) up to 5 (highest having the most desirable conditions). All parameters were weighted equally (weighting factor =6%) with the exception of the four criteria relating to the Sustainability, Resource use, Cost of loss investments and Health- safety risks. These four criteria were allocated a weighting factor of 10% each. The scores and group rankings are based on information and data gathered from the international literature (Linkov (2006), Burgman, M. (2005), Goodwin & Wright, 2009; Lai et al., 2008) and also on personal experience. Figure (10) shows MCA total weight score for different scenarios.

Table 3: MCA for Management Scenarios Evaluation

Primary Criteria and Indicators		Weight	Scenario (1)		Scenario (2)		Scenario (3)		Scenario (4)		Scenario (5)		Scenario (6)		Scenario (7)	
			Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Technical Criteria	Performance and durability	6%	4	0.24	4	0.24	4	0.24	4	0.24	4	0.24	4	0.24	4	0.24
	Flexibility and adaptability	6%	4	0.24	4	0.24	4	0.24	4	0.24	3	0.18	4	0.24	3	0.18
	Resources availability	6%	4	0.24	4	0.24	2	0.12	2	0.12	2	0.12	3	0.18	3	0.12
	Sustainability	6%	4	0.40	4	0.40	1	0.10	1	0.10	1	0.10	2	0.10	1	0.10
Technical criteria total weight			22%		22%		14%		14%		13%		17%		14%	
Environmental Criteria	Surface water quality	6%	2	0.12	2	0.12	2	0.12	2	0.12	4	0.24	5	0.30	5	0.30
	Protection of ground water	6%	3	0.18	4	0.24	3	0.18	3	0.18	3	0.18	3	0.18	3	0.18
	Protection of land stability	6%	3	0.18	4	0.24	3	0.18	3	0.18	3	0.18	3	0.18	3	0.18
	Protection of river habitat	6%	3	0.18	4	0.24	4	0.24	4	0.24	3	0.18	4	0.24	4	0.24
	Resources use	10%	3	0.30	4	0.40	3	0.30	3	0.30	3	0.30	3	0.30	3	0.30
Environmental criteria total weight			19%		25%		20%		20%		22%		24%		24%	
Economical Criteria	Initial Cost	6%	3	0.18	4	0.24	5	0.30	5	0.30	3	0.18	2	0.12	2	0.12
	Operation/ Maintenance cost	6%	4	0.24	4	0.24	5	0.30	5	0.30	3	0.18	4	0.24	3	0.18
	Cost of loss investments	10%	3	0.30	3	0.30	2	0.20	3	0.30	2	0.20	3	0.30	2	0.20
Economical criteria total weight			14%		16%		16%		18%		11%		13%		10%	
Social and Community Criteria	Health and safety risks	10%	3	0.30	3	0.40	4	0.40	4	0.40	3	0.30	4	0.40	3	0.30
	Stakeholders acceptability	6%	4	0.24	4	0.24	3	0.18	3	0.18	3	0.18	4	0.24	4	0..24
Social & Community criteria total weight			11%		11%		12%		12%		10%		13%		11%	
Management scenario total weight score			66.80%		73.60%		62.00%		64.00%		55.20%		67.20%		58.80%	

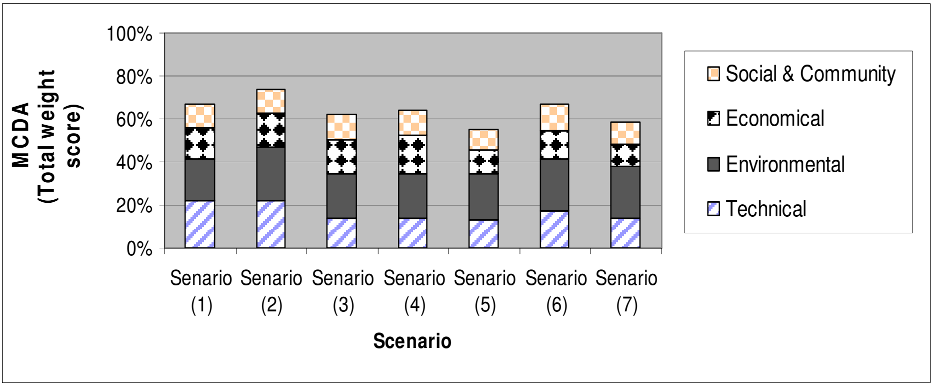

Figure 10: MCA Total Weight Scores

It can be noted from MCA illustrated in table (3) and figure (10) that:-

- MCA total weight score for various management scenario were found 73.60%, 67.20% , 66.8%, 64.00%, 62.00%,58.80%, and 55.20% for scenario (2), (6), (1), (4), (3), (7) and (5) respectively.
- Scenario(2) for DWPs sludge treatment has the highest overall weight score, total technical and environmental weight scores. This scenario can be considered as the most convenient scenario for study area water quality management.
- Scenario(1) for treatment of study area drains by using wetland technique has a relatively high technical criteria weight but a relatively low social & community criteria weight due to effect of stakeholders acceptability ,Health and safety risks sub criteria evaluation.
- Scenarios (4), (3) and (2) respectively have the highest economical criteria total weights.
- Scenarios based on increasing Nile discharge at low flow month such as scenarios(3), (5) and (7) have a relatively low technical criteria total weight due to their sustainability sub criteria inverse effect on compliance with current water management strategy.
- Scenario (6) for treatment drain discharge by construction wastewater treatment plants has a relatively high technical weight but a relatively low economical weight.

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Innovative closed loop wastewater management: The large scale application of the HAMBURG WATER Cycle® at the Jenfelder Au, Hamburg

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HAMBURG WASSER

Abstract

Recent challenges for the water management utilities require innovative ideas to ensure high quality wastewater management in the future. Climatic and demographic changes demand a reorientation of thoughts and actions.

In urban areas, even though the population grows, less water is consumed so that some sewer systems are under certain circumstances not sufficiently flushed. In rural areas small amounts of wastewater are transported over large distances to centralized wastewater treatment plants. More people regularly consume pharmaceuticals that accumulate in the wastewater due to an ageing society. Furthermore in water scarce regions the water which is available has to be used more efficiently.

Instead of optimising the currently established pipelines and treatment plants, a reinvention of wastewater treatment methods to meet the idea of a water cycle principle is a forward-thinking and pathbreaking approach.

The HAMBURG WATER Cycle® (HWC) is an innovative and integrated wastewater management concept that is designed to deal with the before mentioned challenges in a highly sustainable manner.

Based on source separation of the three streams blackwater, greywater and stormwater and a decentralized onsite treatment it closes the water-nutrient-loop by using the individual properties of the different streams in the most efficient way.

As of today, the treatment of wastewater is an energy intensive process. Sewage treatment plants are accountable for up to 20 % of the municipal energy consumption [Umweltbundesamt, 2009]. Many wastewater treatment plants are developing concepts to become self sufficient. With its decentralized approach the HWC takes energy and

resource efficiency one step further. The application of the HWC allows energy generation from blackwater, turning wastewater management into an energy positive process.

In the urban development area Jenfelder Au in Hamburg the first large scale application of the HWC is currently installed. In collaboration with the Hamburg municipality and researchers from different universities, HAMBURG WASSER is currently setting up the HWC concept for more than 2000 future inhabitants. Further refinements of the HWC and individual solutions were designed to implement the HWC at such a large scale. The project is still under construction but is going to deliver invaluable information about the applicability of the HWC on a large technical scale in the future.

1 The HAMBURG WATER Cycle®

The HWC is a concept based on the separation of blackwater, greywater and stormwater which are then utilized and treated due to their individual properties. In contrast to conventional sewer systems where all household effluents are treated together, the HWC collects the toilet wastewater separately from other domestic wastewater. The third water stream considered in the HWC concept is stormwater which does not get into contact with domestic wastewater.

An innovative element of the HWC design is the highly specialized treatment of each stream. The combination of the three smaller wastewater loops creates one efficient and innovative water-energy-nutrient cycle. Figure 1 shows the basic concept of the three wastewater loops.

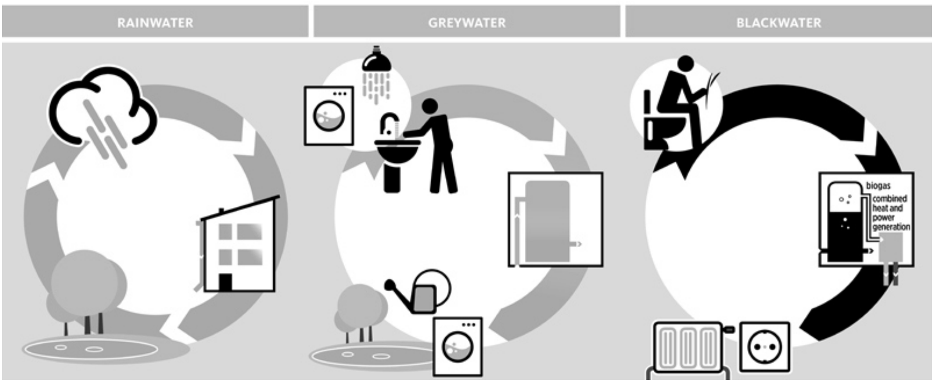

Figure 1: Basic concept HWC

The HWC concept focuses on a decentralised approach of wastewater treatment. First and foremost the energy and heat generated can be used directly on side. But the decentralised installation of water cycles has even more advantages. For example new neighborhoods or areas that are not yet connected to the wastewater system (e.g. in developing countries) are predestined for an approach like the HWC that is designed for a single neighborhood. Furthermore a progressive patch-like introduction of new wastewater treatment methods probably yields the best acceptance and divides the renewal process of sanitation systems into manageable steps because it does not require an exchange of the entire sewer system at once.

1.1 Blackwater

Blackwater is the most polluted wastewater stream and is collected from toilets. But blackwater is also the stream with the highest content of energy because it carries a high amount of organic matter and microorganisms. Furthermore blackwater contains nutrients. For example 75-90 % of the phosphorus contained in household effluents can be found in the blackwater (von Horn et al., 2010).

Because of the high COD content the blackwater carries a value. Normally this value is literally watered down by greywater. A concentrated and separate collection of blackwater as suggested by the HWC appreciates the internal value of blackwater and allows the recovery of energy and nutrients from this stream.

Energy recovery from blackwater in the HWC is achieved through anaerobic fermentation of the blackwater. The generated biogas can then be used on-site for combined heat- and electricity production.

1.2 Greywater

The largest volume of domestic wastewater, greywater, originates from for example kitchen sinks and showers.

Generally greywater is less polluted than blackwater because it contains less pharmaceutical residues and a lower bacterial load. It can be treated with a significantly smaller investment of energy than mixed sewage. This has an even greater impact on the overall cost- and energy efficiency of the HWC because greywater on average has a more than tenfold higher volume flow than blackwater from vacuum collection.

As suggested by the HWC the greywater can be treated decentrally with cost efficient and easy to implement methods such as trickle filters which closes the water loop. In water scarce regions greywater reuse for example to flush toilets is possible. For the highest degree of implementation of the HWC concept it is therefore desirable to treat and reuse the greywater onsite.

1.3 Stormwater

Stormwater requires very little treatment if it is collected separately from the other wastewater streams. Very often in conventional wastewater management separate collection of stormwater is already applied. However there are still combined sewers in use that collect all wastewater streams together for treatment in a wastewater plant.

Unpolluted surface areas lead to rainwater that contains almost no pollutants. The goal of the HWC is to use rainwater as naturally as possible and onsite. The recirculation of rainwater into natural water cycle enhances the microclimate while it is also in line with the HWC to use water bodies as a design element of the area and enhance the recreational and aesthetical value.

2 The project “Jenfelder Au”

The project area “Jenfelder Au” in Hamburg proved to possess ideal conditions for the first large scale technical application of the HWC. Formerly, military barracks were situated at the 35 ha urban development area. Required in the urban development plan for the area was to develop an attractive and sustainable neighbourhood with diverse building types, recreational areas and water bodies. The overall concept has an exceptional focus on social as well as ecological sustainability. Implementing the HWC as part of the urban development concept in this area emphasizes the demand for and interest in new sanitation concepts.

The goal of the HWC project Jenfelder Au is to create a large-scale application of the HWC. More than 600 households with over 2000 inhabitants are going to be connected to the HWC. As the biggest source separation project in Europe to date, the project serves as a flagship project for the HWC that can be refined to meet different needs in urban, rural or water scarce regions. The innovative concept gained funding from the European Commission LIFE+ programme as well as from the Federal Ministry of Economics and Energy. Furthermore it is part of the research project KREIS (Kopplung von regenerativer Energiegewinnung mit innovativer Stadtentwicklung), which receives funding by the German Federal Ministry of Education and Research.

2.1 Collection of Blackwater

Even though the HWC considers each stream separately, the blackwater collection and treatment is the most innovative technical element of the HWC. For the large scale application in the project Jenfelder Au it has been further developed and refined.

Vacuum collection of the blackwater was introduced into the original concept as an innovative element for the implementation of the HWC in the project area Jenfelder Au. The collection of blackwater with negative pressure results in a very concentrated stream of blackwater because vacuum toilets use less than 1 L of water per flush. In the concentrated blackwater the COD concentration can be as high as 9000 mg/L and the dry matter has an approximate concentration of 7000 mg/L. It is expected that per person and day 6-8 L of concentrated blackwater are generated.

Because of the higher concentration of organic matter the concentrated blackwater is even better suited for energy generation through anaerobic fermentation. No upconcentration steps are required to utilize the blackwater for the fermentation process. Thus the vacuum collection of blackwater proves to be an invaluable addition to the HWC concept.

Another advantage of the vacuum collection together with the decentralized treatment of the blackwater is the short retention period in the pipelines. With the quick transport the unwanted decomposition of the blackwater in the pipelines is minimized which adds to the value of the blackwater as an energy source.

2.2 Technical design vacuum system

The design of the vacuum sewers as transport pipelines is of utmost importance for the central idea of a water-nutrient cycle. The blackwater has to be collected for fermentation and should maintain the properties of high energy and nutrient concentration during transportation.

The project Jenfelder Au is the first installation to collect blackwater with negative pressure sewers at such a large scale. Thus the technical design of the pipelines and vacuum vessels had to be custom tailored to meet the demands of a highly reliable and maintainable collection system. All of the decisions regarding the vacuum network for the project Jenfelder Au were made on the basis of extensive testing or according to established guidelines.

The central vacuum station, located at the depot of the Jenfelder Au area contains the vacuum pumps and vacuum vessels. A negative pressure between -0,4 bar and -

0,8 bar is generated here. The transport mechanism of vacuum pipelines is the difference of the negative pressure at the vacuum station and the atmospheric pressure where the blackwater enters the pipeline. In the pipelines the blackwater forms a plug that inhibits pressure balance before and after the plug which is the driving force for the transport.

For the large scale application of vacuum sewers in the Jenfelder Au the pipelines were custom designed with a special profile that facilitates blackwater transport. If the blackwater does not take up the whole diameter of the pipelines, the pressure balance will inhibit further transport of the water. To avoid this, the profile of the pipelines is designed with a saw tooth profile. Characteristicly for this profile are slope differences in the pipelines. Longer regions with small downward slopes alternate with short, steeper slopes. The lows after the downward slope regions in the pipelines serve to collect enough blackwater to keep the water plug consistent and retain the pressure difference. With this special network design the vacuum sewers follow or outperform the guidelines of the DIN EN 1091 standard for vacuum sewerage systems outside of buildings and DWA 116-1 Besondere Entwässerungsverfahren, Teil 1: Unterdruckentwässerungssysteme außerhalb von Gebäuden (Special Sewerage Systems, Part 1: Vacuum Sewerage Systems Outside Buildings) (DWA, 2008).

The guiding principles for the design of the vacuum system were easy maintenance and reliability. To guarantee permanent supply with negative pressure there is a total of 20 % redundancy in the pipeline system. Three main lines form two subnetworks with several gate-valves between the main lines. The interconnectivity of network parts allows a flexible operation of the vacuum sewers. Each subnetwork is designed to have minimal hydraulic pressure losses. Figure 2 shows the network design of the vacuum sewers.

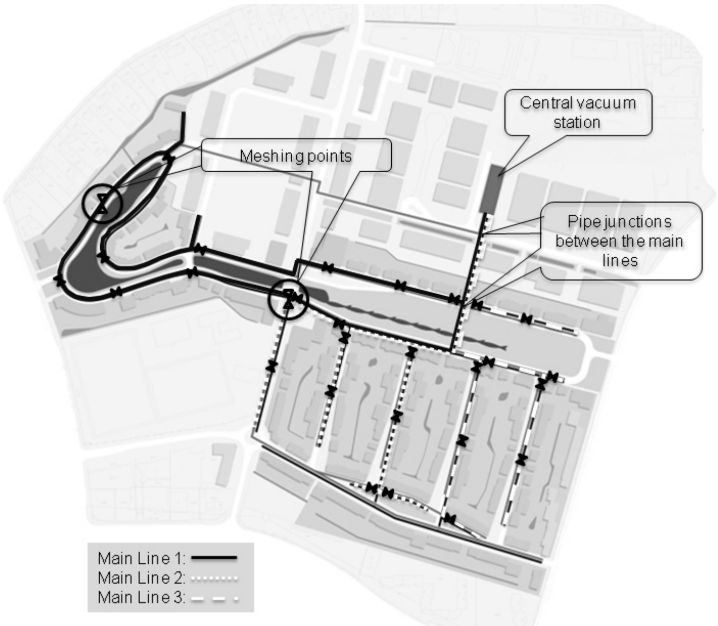

Figure 2: Vacuum network design with main lines

To facilitate maintenance of the vacuum sewers, inspection units are installed every 20 to 50 metres. Moreover the pressure throughout the vacuum network is monitored with approximately 80 pressure switches. This equals one pressure switch for every 4-6 households and is estimated to have the best efficiency in monitoring with reasonable running costs.

In case of a pressure change the switch closest to the malfunction reacts first. Thus problems can be located quickly and only the affected area can be separated with shut-off valves from the vacuum network for the duration of the blockage.

The vacuum station has two redundant vessels and each vessel is operated by two independent vacuum pumps. In case of maintenance or technical errors the negative pressure can be upheld by one of the vacuum vessels. The result is a 100% redundancy at the vacuum station.

A further advantage of two separately operating vacuum vessels is the possibility to operate the pumps with different pressures. To account for the different properties in the subnetworks regarding length of the pipelines and elevation the vacuum vessels will be operated in an adapted operation mode. Under normal working conditions each vacuum vessel is going to generate a different negative pressure for one of the two subnetworks. This operation mode will save about 30 % of energy compared to a single pressure operation mode [Schönfelder et al., 2013].

2.3 Blackwater treatment: Anaerobic fermentation and energy generation

The blackwater treatment plant is located at the depot of the Jenfelder Au area. Decentralized treatment is the first choice for a closed-loop system because the transport distances are kept at a minimum. Together with co-substrates such as green cuttings and grease trap residues the blackwater is fermented in an anaerobic reactor.

With a volume of 750 m^3 the fermenter is dimensioned to be loaded with 6-8 L blackwater produced per person and day. In addition to blackwater, co-substrates like grease-filter residues and green cuts are going to be added to the fermenter. For the choice of possible co-substrates the local availability was the main selection criterion. Only short transport distances can guarantee a sustainable energy generation in the fermenter.

In a combined heat and power process the biogas will be utilized to produce heat that can be used directly in the neighborhood as well as electricity.

2.4 Greywater treatment

The greywater in the HWC project Jenfelder Au is collected in conventional gravity sewers. This resonates with the properties of the greywater stream that has a higher volume flow than blackwater but is less polluted.

Several cost and energy efficient cleaning methods for the greywater treatment in the Jenfelder Au were discussed. For example it would be possible to clean the greywater with trickling filters. Because greywater is less polluted than mixed domestic wastewater it can be cleaned with less effort. This contributes to the advantages of a source separation sanitation concept.

Research on optimal onsite greywater treatment to close the water loop will be integrated into the project as soon as the first inhabitants live in the Jenfelder Au area.

2.5 Rainwater management and landscape design

One of the main goals of the HWC is near natural rainwater management. Around 20 % of the project area are unsealed green spaces. Rainwater can evaporate and seep into the ground. In the project area an overall design concept was created to use the water bodies as aesthetically pleasing design elements of the urban landscape. For the storage of rainwater a retention pond was integrated into the building area. The design of the “Kühnbachteich” is attractively integrated into the neighborhood. Rainwater in the HWC project Jenfelder Au is transported in open channels to the “Kühnbachkaskade” which are streams and cascades. From there it gets to the main retention pond “Kühnbachteich”.

The integration of the water bodies into the living area serves the idea of the HWC that water should be part of the urban landscape because it enhances the microclimate. Additionally it includes aspects of social sustainability because attractive water bodies are used for visual improvement of the neighborhood and as public recreational areas.

The implementation of retention ponds optimizes flood protection: In cities the rain often has to seep into the ground quickly because the unsealed areas are comparatively small. Permanent retention basins and detention areas for rainwater can compensate for the smaller urban percolation surfaces in case of heavy rainfalls. The drainage layer underneath the retention ponds serves as a simple cleaning step for the nearly unpolluted rainwater before it seeps into the ground.

2.6 Challenges

While the technical design and implementation of the HWC in the Jenfelder Au project required careful planning and testing the non-technical challenges outnumbered the technical challenges. The main areas of non-technical challenges can be categorized into stakeholder communication and legal framework for vacuum sanitation.

Stakeholder communication is regarded a key feature for the overall success of a large scale urban development program. Different communication approaches conducted by HAMBURG WASSER were aimed at gaining acceptance and approval of the HWC from the different stakeholders such as architects and future inhabitants [Wuttke, 2015].

The Hamburg wastewater law (Hamburgisches Abwassergesetz, HmbAbwG) had to be amended to include regulations about vacuum sanitation systems and source control. Already in 2010 the legal department of HAMBURG WASSER started the amendment process which is still ongoing. To avoid delay of the implementation because of a lack of legal coverage an agreement in the purchase contracts covers the mandatory installment of the HWC in the Jenfelder Au area by private law.

To maintain the negative pressure necessary for the transport of the blackwater, the vacuum toilets and pipelines on private ground have to be fully functional. The responsibility of HAMBURG WASSER ends at the border to private ground. Thus shut-off ball valves are installed at the borders between public and private grounds to be able to control the functionality of the vacuum sewers and maintain negative pressure for the entity of the vacuum network even if technical components on private ground are temporarily out of order. Figure 3 shows an overview of the public and private components of the HWC in the Jenfelder Au area.

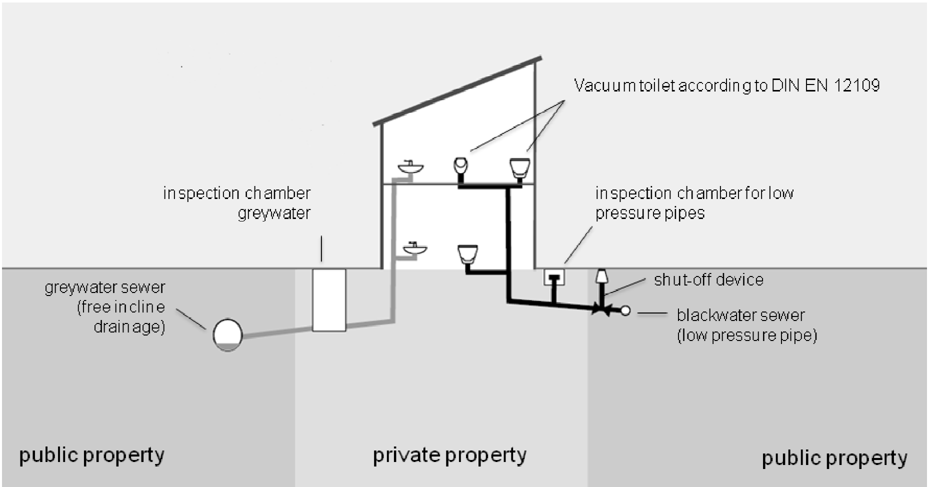

Figure 3: Public and private components of the HWC

Overall the management of the non-technical challenges connected with the implementation of the HWC outnumbered the technical challenges and required attentive communication and clear responsibilities.

2.7 Current status of the project

The construction phase of the project Jenfelder Au started in October 2013 with the groundbreaking ceremony. Construction of the pipelines for drinking water as well as the greywater sewers and the vacuum sewers for blackwater belong to the first construction phase. Together with the building for machinery and equipment at the depot that also holds the vacuum vessels these installations will be completed by the end of 2015. Figure 4 shows the installation of the vacuum vessels after their delivery in April 2015.

In 2016 the plants for blackwater treatment will be constructed as part of the second construction phase. From the end of 2016 the first inhabitants are expected to move in.

3 Summary

The combined water and energy cycle that emerges from the HWC concept has been refined for a large scale technical application that combined source separation with vacuum sanitation and is unique in its technical concept and scale. To achieve a minimization of possible technical failures the vacuum network was carefully designed to eliminate as many problems as possible beforehand.

Challenges that had to be faced over the course of the project installation included legal challenges and the coordination of stakeholder interests. The awareness of possible problems in this area facilitated finding solutions with the involved parties and allowed to stay focused on the overall project idea of a water-energy-nutrient cycle in a sustainable neighbourhood.

When the installation is complete and running, interesting data on the rate of energy and heat coverage by blackwater fermentation will be generated.

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Struvia™ Technology for Phosphorus Recovery

Martin Brockmann, Boris Lesjean, Sylvie Novak,

Abstract

Keywords: Phosphorus, Struvite, Waste Water, Recovery, Dewatered Sludge

A wastewater treatment plant has to remove nitrogen and phosphorus (P) in order to protect the environment from eutrophication (algae blooming). In general, chemical precipitation (with metal salts) is necessary to reach a low level of P in the effluent. This phosphate, precipitated as salt in the sludge, is only partly available to plants. On the other hand, this nutrient is essential for agricultural use. There are no fossil resources available in Germany, so phosphorus must be imported in large quantities from those few countries having the export monopoly. Phosphorus is one of the fertilizers which are mandatory to improve agricultural production. From a political point of view, phosphate rock is now rated as one of the 20 critical raw materials for the EU. Concepts are therefore developed to enable the technical recovery and valorization of phosphorus from wastewater sludge.

At the WWTP of Braunschweig, liquor returns from sludge dewatering may cause overload situations during the winter period. Instead of removing nutrients by extending the capacity of the conventional WWTP or enlarging the use of chemicals, the local wastewater association (Abwasserverband) has opted for a solution facilitating the recycling of nutrients. In the near future, a thermal hydrolysis will be built, further increasing the nutrient loads in the liquor_-returns. The centrate will be treated to remove P as struvite and N as ammonium disulphate. This is done both to unload the plant and then limit the investment, as well as to create products that can be reused in the local economy as a first step towards circular economy.

This paper will describe the results of pilot tests performed to recover phosphorus from the centrate of a municipal WWTP (Braunschweig) through the Struvia™ process developed by Veolia. Phosphorus is recovered as struvite (Magnesium-Ammonium-Phosphate salt, MAP) and will be reused as one basic component for fertilizer production.

The Struvia™ pilot plant of Veolia Water Technologies was commissioned in December 2014 and operated until end of March 2015. Target of the tests was an evaluation of several operating conditions in order to find the optimal way to precipitate struvite in a quality suitable to be reused by the fertilizer manufacturers.

For the 3-month test period two centrate qualities from dewatering of digested waste activated sludge (WAS) were tested. WAS was digested under mesophilic conditions and centrate was stored in staple tanks. The pilot-plant treated between 0.3 and 0.6m³/h centrate in continuous operation.

The following main parameters were tested: P-concentration, HRT, SRT, pH and molar ratio:

- With centrate A: three different HRT's without pH adjustment were tested in order to optimize the molar ratio between Mg and P.
- With centrate B: Adjustment of pH by NaOH dosing or aeration, influence of SRT.

The preliminary results show a stable removal rate around 95 %. The soluble P was recovered by the Struvia™ plant at a mol/mol ratio of less than 1.2. The produced struvite is of white and fine-sandy appearance. The quality of the struvite is lab-tested for microbiology, organic compounds and heavy metals. Batches of the struvite were given to fertilizer companies for blending into their granular product. In contrary to other P-recyclates (such as ash-based products), struvite is very well assimilable by plants due to its high solubility. The product is therefore suitable as an agricultural fertilizer.Introduction

1 Introduction

The sewage treatment plant KA Steinhof treats the waste water from the city of Braunschweig and the surrounding communities and is operated by the local Veolia subsidiary SE|BS. The design capacity of the plant is 275,000 PE; currently the amount of about 350,000 PE is treated.

The amount of waste water to be treated passes through several cleaning stages, e.g. mechanical pretreatment, primary settling and nitrification/denitrification including biological phosphorus removal. Both resulting sludges, primary and WAS, are stabilized anaerobically. The resulting biogas is used to generate heat and electricity.

The Abwasserverband Braunschweig wants to optimize the sludge treatment. Therefore the introduction of a thermal hydrolysis step is planned, with the following objectives:

- reduce the amount of sludge to be disposed
- generate more biogas and more energy
- recover nutrients (N and P) to a higher extent for economic recovery

The thermal hydrolysis will destroy bacterial cells. Organic fraction will be digested while phosphorus and nitrogen levels are increased in the return flow to the headworks. To avoid critical situations and for meeting the discharge limits all the time, it is planned to recover these nutrients from the return flow for agricultural use.

The objective of the pilot trials with the Struvia^{TM} technology was to demonstrate the performance of the process and the quality of the product produced from reject water of sludge centrifuges.

2 Struvia^{TM} Pilot Plant

2.1 Background

Struvite is a rarely occurring mineral crystallized from ammonium, phosphate and magnesium as [(NH4) Mg (PO4) + incorporated water]. Due to the sparingly soluble connection of ammonium and magnesium it dissolves slowly in the ground and is therefore available for a long time as crop fertilizer.

The reject water contains high concentrations of ammonium and phosphate, but only a very small amount of magnesium, which is therefore dosed as magnesium chloride solution. The reaction takes place at pH 8-8.5 and generates an acidification of the water:

$$Mg^{++} + NH_4^{+} + H_nPO_4^{n-3} + 6\ H_2O \rightarrow (NH_4)Mg(PO_4).6(H_2O) + n\ H^{+}$$

The precipitation is quick and produces small sand-like crystals that can be simply decanted and dried.

2.2 Description of the StruviaTM Pilot Plant

The reject water to be treated is taken from a holding tank (1) and pumped in the reactor (3), necessary chemicals (2) are added (magnesium chloride and optionally sodium hydroxide).

The reactor consists of a continuous mixed main part, which is equipped with a lamella pack on top. This concept (Veolia patent) avoids an additional separation step and reduces the risk of clogging in pipes.

The crystals produced are decanted in the reactor and are extracted regularly. The struvite will then be stored in an intermediate drying container (6).

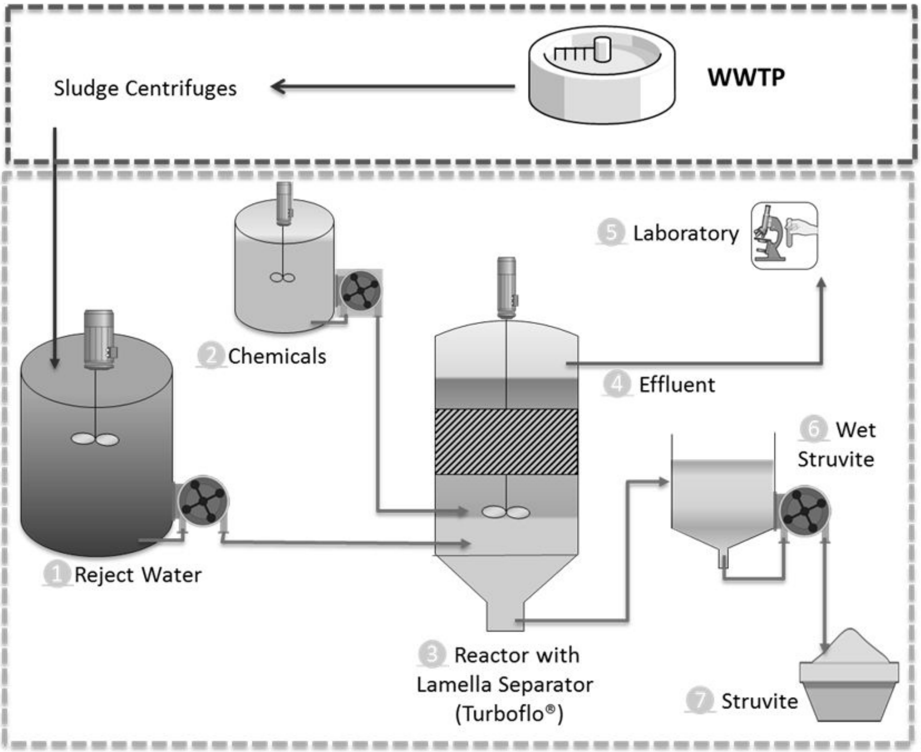

Figure 1: Flow scheme of the Pilot Plant

The process is controlled via pH-probes and turbidity sensors both in the reactor and in the effluent (4). The tanks are equipped with level probes; the inflow into the reactor is directly measured and controlled.

During the process various analytics (5) are carried out in inlet and outlet, separate analytics for the gained product (7) will finally prove the quality produced.

2.3 Conditions for tests

Two different reject water samples were used as feed for the pilot plant. The quality in terms of remaining solids was good. Phosphorus and nitrogen contents were about 300 mg/L PO_4-P and 1200 mg/L NH_4-N, respectively.

- Period 1 (P1): December 2014 until mid-February 2015: centrate 1
- Period 2 (P2): mid-February until the end of March 2015: centrate 2

Centrate 2 showed a significantly higher P concentration than centrate 1.

Table 2: Analytics for the centrates

Parameter	Centrate 1	Centrate 2
pH	8.5 - 8.6	8.3 - 8.5
Conductivity (mS/cm)	9.1	10,0 - 10.5
TSS (mg/L)	approx. 20	ca. 60 - 120
Dry matter (g/L)	2.3	2.9 - 3.1
COD (mgO_2/L)	approx. 620	750 - 900
NH_4-N (mg/L)	approx.1200	ca.1300
$P_{tot.}$ (mg/L)	approx. 320	380 - 410
PO_4-P (mg/L)	330 - 340	ca. 420
Alkalinity (mmol/L)	approx. 80	90 - 95
Mg (mg/L)	< 2	ca. 2.5
Ca (mg/L)	approx. 18	23 - 26
$COD_{fil.}$	n.n.	750 - 820

The aim of the tests was to determine the optimal settings for optimized MAP precipitation. The following parameters and operation modes were investigated:

- Mg/P ratio (period 1)
- Hydraulic retention time (period 1)
- pH value (period 2)

3 Results

3.1 Precipitation

Period 1: Hydraulic residence time was set to 45 and to 60 minutes, resulting in a good P removal at both settings. Using Mg/P ratio at a range of 1.1-1.2 led to stable P-reduction of 90% and higher.

With a very stable process performance, P-removal of 90 to 95% was achieved. This reduced the phosphorus content down to less than 30 mg PO_4-P/L. Based on NH_4-N, yield was 16-17% (reduction to about 200 mg/L).

Period 2: The optimum pH range was between 7.5 and 8. In order to ensure the yield, slightly more magnesium was dosed compared to the stoichiometric ratio: Mg/P ratio between 1.1 and 1.2 was sufficient.

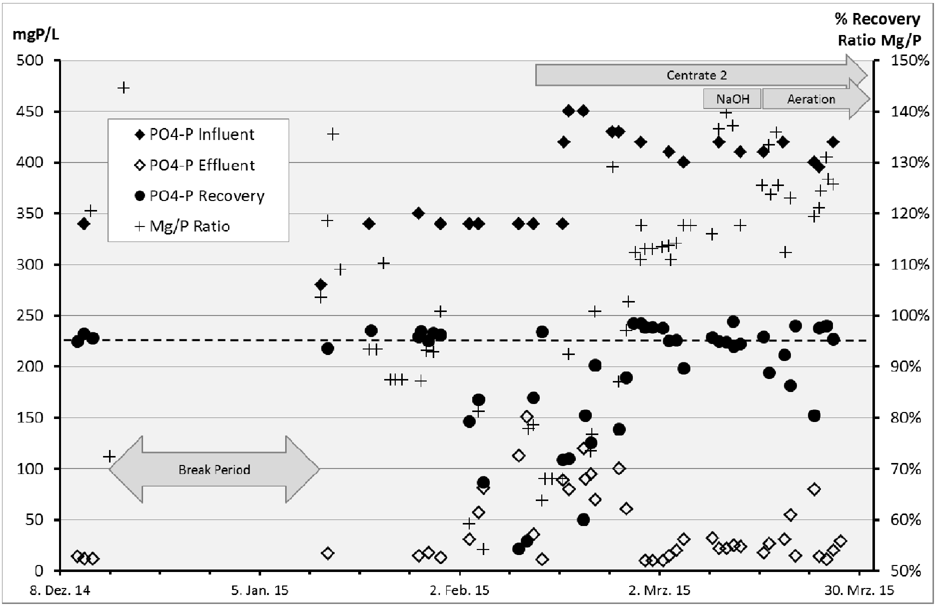

Figure 2: Settings for P-recovery

At the end of the experiment, controlled addition of sodium hydroxide solution in the reactor was investigated and compared with pre-aeration. It was found that aeration increased pH by about 0.3-0.4.

Pre-aeration proved to enable good operation conditions in the reactor and to provide good MAP precipitation

3.2 Product quality

The product is sand-like and of homogeneous appearance. The color is bright and there are no dark particles. The material already dried in the bag to 80% - 90% on the surface. But even after two weeks drying is not homogeneous through the depth of the bag (more wet at the bottom).

Five samples were taken and analyzed for their grain size at the BAM in Berlin. In general struvite samples were taken after 5 days of stable operation

Evaluation of homogeneous size distribution was done by calculating the degree of uniformity of one sample (d60/d10). Below a value of 4.5, it is assumed that the corresponding sample is homogeneous. In four of five samples this value could be achieved with a mean particle size between about 100 up to 260 µm.

Table 2: Analytics of particle size

sample	d10	d50	d60 (estim.)	d90	d90/d10	d60/d10
A	145 µm	276 µm	310 µm	467 µm	3,2	ca. 2,1
B	95 µm	260 µm	290 µm	463 µm	4,9	ca. 3,1
C	88 µm	231 µm	260 µm	413 µm	4,7	ca. 3,0
D	23 µm	311 µm	380 µm	580 µm	25,2	ca. 16,5
E	61 µm	97 µm	105 µm	142 µm	2,3	ca. 1,7

Sample D, however, was very heterogeneous. This is certainly caused by the presence of remaining crystals from the prior settings and newly created crystals under addition of sodium hydroxide.

Two of these five samples (A and E) were also analyzed for their chemical composition and release of phosphorus.

Table 3: Chemical compounds

Sample	C %	H %	N %	Mg %	P %	Ca ppm	K ppm	Na ppm
Theory	*0,00*	*6,57*	*5,71*	*9,9*	*12,6*	-	-	-
Reference	*0,14*	*6,31*	*5,64*	*n.c.*	*n.c.*	-	-	-
A	0,32	6,65	5,5	9,98	12,55	721	1121	944
E	1,06	6,57	5,43	9,66	12,24	721	1571	801
Detection limit	-	-	-			516	124	154

The produced struvite clearly shows a CHN-composition very close to theoretical values of pure MAP and to the reference product of the laboratory (MAP 98%, Alfa Aesar no. 10139565). In addition, only very small amounts of organic carbon could be detected, even sample E although it was produced from a centrate with a higher content of suspended solids.

Magnesium and phosphorus contents are also close to theoretical values (respectively 99 g/kg and 126 g/kg based on the chemical formula). Other elements incorporated are potassium, sodium, calcium.

All other detectable elements were present as traces only. Therefore the struvite produced has no exposure to heavy metals and is suitable for agricultural use in accordance with the current legal requirements (e.g. fertilizer-ordinance DüV).

The solubility of phosphorus in the soil (Pnac, i.e. in neutral ammonium citrate-soluble phosphate) was in any case above 50%, so that the product will be very suitable for agricultural use.

Finally a second laboratory (Institut Dr. Nowak) investigated the microbiological safety of the product. Five independent samples were taken after a storage period of several weeks. In no case any pathogens (neither salmonellae nor faecal coliforms) were found above detection limit (Figure 3).

All analytics and investigations prove the very high quality of the product and its benefit in agricultural use.

Prüfbericht Nr. 15–13060

Kunde			**Kunden–Nr. 12266**
Name:	Abwasserverband Braunschweig	Auftrags–/Bestell–Nr.:	
Ansprechpartner:	[illegible]	Untersuchungsanlass:	Eigenüberwachung

Probe/Prüfgegenstand	
Art der Probe:	Klärschlamm
Probenahmezeitpunkt:	01.07.2015
Probenahmeart:	Probe über Paketdienst angeliefert
Probenehmer:	übernommen
Untersuchungszeitraum:	von: 03.07.2015 bis: 08.07.2015

Messstelle / Beschreibung
Produkt Probe 5
AFS , Sack BS Zentrat 2 Struvit
01.07.2015

Parameter	**Ergebnis**	**Einheit**	**Verfahren**
Probe über Paketdienst angeliefert			
Fäkalcoliforme Bakterien (FC)	<30	MPN in ml	BGK–Methodenbuch
Salmonella sp.	negativ	qualitativ	BGK–Methodenbuch V.1.1.3

Bewertung: Die Probe ist mikrobiologisch nicht zu beanstanden.

Figure 3: Quality certificate on hygienic parameters

4 Conclusion

The Struvia™ process allows a good recovery of phosphorus (90-95% elimination from the centrate) at a short hydraulic retention time of up to one hour. The effluent concentration of dissolved phosphorus is below 30 mg PO_4-P/L, when the Mg/P ratio is about 1.1 - 1.2 and pH is about 7.5.

The sludge from the Struvia™ process consists of 98% of struvite. It is built from fine sand-like crystals with a homogenous particle size distribution. The struvite crystals dry quickly. The struvite has only minimal loads of heavy metals and germs. In contrary to other P-recyclates (such as ash-based products), struvite is very well assimilable by plants due to its high solubility. The product is therefore suitable as an agricultural fertilizer, either as a secondary raw material for fertilizer production, or directly after granulation.

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Simultaneous improvement of biological wastewater nutrient removal and reduction of greenhouse gas emission by using waste sludge derived carbon source

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Abstract

Activated sludge process is the most widely used method for municipal wastewater biological nutrient removal (BNR). However, this process produces large amounts of waste activated sludge (WAS) and greenhouse gas. Also, the performance of BNR in China is unsatisfied due to the low influent carbon source. Here we show that WAS can be efficiently converted to BNR preferred carbon source via anaerobic co-fermentation with kitchen waste. After fermentation, the released nitrogen and phosphorus were recovered. It was found that the use of sludge fermentation liquid, compared with that acetic acid, not only significantly improved nutrient removal efficiency, but remarkably reduced N_2O generation. The main reasons for BNR performance being enhanced while N_2O emission being decreased by sludge fermentation liquid were due to the presence of propionic acid and copper ion, which increased the activity and the abundance of BNR key enzymes and microbes.

1 Introduction

It is well known that large amounts of waste activated sludge (WAS) were generated in municipal wastewater treatment plants, and the treatment of WAS has become a significant concern for researchers. Since there are high contents of protein and carbohydrate in sludge, the use of sludge to produce useful products, such as volatile fatty acids (VFA), biohydrogen and methane has attracted much attention (Feng et al. 2009; Zhao et al. 2010, Zhang et al., 2010).

Biological nitrogen and phosphorus removal depends on wastewater carbon source (such as VFA). However, the available VFA in municipal wastewater is usually not enough to ensure satisfied biological nutrient removal (BNR). Thus, production of VFA from WAS has become an attractive hotspot in recent years (Tong and Chen 2007). However, the efficiency of VFA production is usually very low due to the lower carbon to nitrogen ratio (C/N), the poor sludge utilization by anaerobic microbes, and the consumption of VFA by methanogens. Meanwhile, there are significant amounts of ammonia and phosphorus released into the fermentation liquid (Tong and Chen 2009), and the direct use of this fermentation liquid as carbon source would increase the nitrogen and phosphorus loadings of wastewater treatment plants.

In this study the production of VFA-containing fermentation liquid was enhanced by adding kitchen waste to sludge to adjust the C/N ratio, and the released nitrogen and phosphorus in the fermentation liquid was removed by the struvite method. Then the fermentation liquid was utilized as carbon source of wastewater biological nutrient removal. Its performance was compared with that of acetic acid, a commonly used carbon source in the literature. Also, the mechanisms for sludge fermentation liquid showing greater BNR performance and less N_2O and NO generations were investigated.

2 Materials and Methods

Preparation of VFA-containing sludge fermentation liquid by co-fermentation of sludge and kitchen waste

WAS used in this study was obtained from the secondary sedimentation tank of a municipal wastewater treatment plant, and then concentrated by settling at 4°C for 24 h. The main characteristics of the concentrated sludge are as follows: pH 6.8 ± 0.2, total suspended solids (TSS) 19.1 ± 2.2 g/L, volatile suspended solids (VSS) 13.1 ± 1.6 g/L, soluble chemical oxygen demand (SCOD) 0.2 ± 0.03 g/L, total chemical oxygen demand (TCOD) 19.3 ± 0.4 g/L, total carbohydrate 1.9 ± 0.2 g COD/L, total protein 10.5 ± 1.3 g COD/L, and lipid and oil 0.3 ± 0.04 g COD/L. The food waste, consisting mainly of boiled rice, vegetables and meat, was withdrawn from a dining hall in Shanghai. After the facial tissue, chopsticks, bones, and bulk form particles were removed, the food waste was milled to slurry state and diluted with tap water to final TSS 83.5 ± 4.8 g/L, VSS = 79.8 ± 4.5 g/L, TCOD = 132.3 ± 14.1 g/L, SCOD = 39.9 ± 4.9 g/L, total carbohydrate = 79.7 ± 3.8 g COD/L, and total protein = 18.5 ± 1.3 g COD/L. The production of sludge derived VFA was conducted under conditions of C/N 12.1/1, pH 8.2 and time 2.4 d, which had been described in our previous publication (Chen 2013).

Simultaneous removal of the released nitrogen and phosphorus from sludge fermentation liquid

The fermentation of sludge led to the release of large amounts of ammonia-nitrogen (NH_4^+-N) and phosphorus. According to our previous study pH, Mg/N and P/N are the most important variables as NH_4^+-N and soluble ortho-phosphorus (SOP) can be simultaneously removed in the formation of struvite. The optimal conditions for removal of NH_4^+-N and SOP from fermentation liquid of sludge derived VFA have been reported in our previous publication (Zhang and Chen 2009). The main characteristics of the supernatant fermentation liquid after nitrogen and phosphorus removal are as follows (mg COD/L): VFA 10381 ± 302 (including acetic acid 2489 ± 387, propionic acid 7091 ± 516), soluble carbohydrate 178 ± 27, and soluble protein 896 ± 74. Also, it contained SOP 2.6 ± 0.4 mg/L and NH_4^+-N 8.5 ± 0.7 mg/L.

Operation of sequencing batch reactors (SBRs)

Two anaerobic-low DO SBRs (SBR-A and SBR-F), with a working volume of 4 L each, were operated with three cycles per day. Each cycle was 8 h (2 h anaerobic, 3 h aerobic, 1 h settling, 10 min decanting and 110 min idle). The synthetic wastewater (2 L) was pumped into each reactor during the initial 10 min of the anaerobic stage. In the low DO period, air was provided intermittently using an on/off control system with online DO detector keeping the DO level between 0.15 and 0.5 mg/L. Ten minutes before the end of low DO stage, sludge was wasted to maintain the solids retention time (SRT) at approximately 22 d. After settling, 2 L of supernatant was removed from each SBR, resulting in a hydraulic retention time (HRT) of 16 h. Each reactor was constantly mixed with a magnetic stirrer except for the settling, decanting and idle periods. It took 123 d before stable nitrogen and phosphorus removals were achieved in two SBRs.

The synthetic wastewater was prepared daily, which contained (per liter) 5 mL solution A, 2 mL solution B, 1 mL nutrient solution, 3 mL concentrated peptone liquid, and a certain amount of carbon source (acetic acid or sludge fermentation liquid). Solution A contained per liter: 10 g $MgSO_4 \cdot 7H_2O$, 4.5 g $CaCl_2 \cdot H2O$, 93.6 g NH_4Cl. Solution B contained per liter: 29 g KH_2PO_4 and 33 g K_2HPO_4. Concentrated peptone liquid contained 200 g peptone per liter. Nutrient solution contained per liter: 1.5 g $FeCl_3 \cdot 6H_2O$, 0.15 g H_3BO_3, 0.03 g $CuSO_4 \cdot 5H_2O$, 0.18 g KI, 0.12 g $MnCl_2 \cdot 4H_2O$, 0.06 g $Na_2MoO_4 \cdot 2H_2O$, 0.12 g $ZnSO_4 \cdot 7H_2O$, 0.15 g $CoCl_2 \cdot 6H_2O$ and 10 g ethylene-diamine tetra-acetic acid (EDTA). Although the carbon sources of SBR-A and SBR-F were acetic acid and sludge alkaline fermentation liquid, respectively, they had almost the same initial soluble COD (~300 mg/L), NH_4^+-N (~ 30 mg/L), and SOP (~12 mg/L). The initial pH of synthetic wastewater was adjusted to pH 7.4 ± 0.2 by 4M HCl or 4M NaOH.

Effect of the addition of sludge fermentation liquid to municipal wastewater on nutrient removal and NO and N_2O generation

Two SBRs (SBR-MA and SBR-MF), which received municipal wastewater plus acetic acid, and municipal wastewater plus fermentation liquid, respectively, were operated as that described above The municipal wastewater was obtained from the primary sedimentation tank outlet of a wastewater treatment plant in Shanghai, China. Its main characteristics are as follows: TCOD 135-184 mg COD/L, SCOD (soluble chemical oxygen demand) 98-140 mg COD/L, NH_4^+-N 24-29 mg/L, TN 27-33 mg/L, SOP 2.3-4.5 mg/L, and pH 7.2-7.5. The municipal wastewater was added by solution A and solution B (see above description) to get an average initial NH_4^+-N, TN, SOP and TP of 30, 35, 10.8 and 12.1 mg/L, respectively, in two SBRs. The initial SCOD in two SBRs was maintained at approximately 280 mg/L after the addition of acetic or sludge fermentation liquid. The initial pH of wastewater was adjusted to pH 7.4 ± 0.2 by 4M HCl or 4M NaOH.

Effects of main organic components and metal ion (Cu^{2+}) in sludge fermentation liquid on NO and N_2O generation

The following batch experiments were conducted. 5 min before the end of low DO phase, 2 L biomass was taken from SBR-A, centrifuged at 100 g for 30 s to remove the supernatant, washed three times with 0.9% NaCl solution, and then resuspended in tap water with a final volume of 2 L. The aliquot was divided equally into five reactors and then the nutrient solutions, solution A and solution B, were added to each reactor to achieve final calculated concentrations of NH_4^+-N, SOP and Cu^{2+} of 30 mg-N/L, 60 mg/L and 0.00375 mg/L, respectively. The concentration of main organic components in each reactor was (mg COD/L): 250 acetic acid (reactor 1), 65 acetic plus 185 propionic (reactor 2), 64 acetic plus 182 propionic plus 4 bovine serum albumin (BSA, model compound of protein) (reactor 3), 58 acetic plus 166 propionic plus 4 BSA plus 21 glucose (a model compound of carbohydrate) (reactor 4), 58 acetic plus 166 propionic plus 4 BSA plus 21 glucose plus Cu^{2+} (by the addition of $CuCl_2 \cdot 6H_2O$) of 0.01 mg/L (reactor 5). There was Cu^{2+} due to the use of nutrient solution, and its calculated concentration was 0.00375 mg/L, which was added in reactors 1-4. As the concentration of Cu^{2+} was 0.01 mg/L after sludge fermentation liquid was used, thus this amount of Cu^{2+} was added to reactor 5. The sludge mixture in all reactors was stirred under anaerobic condition for 120 min, and then aerated for 180 min with DO of 0.15-0.5 mg/L.

Analytical methods

The analyses of COD, NH4+-N, NO3--N, NO2--N, TN, SOP, TP, VFA, protein, carbohydrate, mixed liquid suspended solid (MLSS), mixed liquid volatile suspended solid (MLVSS), nosZ gene, and activities of nitrite, nitric oxide and nitrous oxide reductases were detailed in a previous publication (Zhu and Chen, 2011). The N2O and NO in both gas and liquid phases were measured by the micro sensors (Unisense, Aarhus, Denmark), and their generation rates were calculated according to the reported method (Kampschreur et al., 2008). Heavy metals were detected by plasma-optical spectrometry (Perkin Elmer, Optima 2100DU).

3 Results and Discussion

Comparison of nutrient removal and NO and N_2O Generation after addition of sludge fermentation liquid and acetic acid to municipal wastewater

As seen in Figure 1A, the use of sludge fermentation liquid, compared with acetic acid, as additional carbon source did not significantly affect the removal of ammonium nitrogen. However, both total nitrogen and soluble phosphorus removal efficiency was grater in the reactor with sludge fermentation liquid as supplemental carbon source (84.6% versus 63.8%, and 97.2% against 76.5%). The data in Figure 1B showed that with acetic acid as the additional carbon source the generated N_2O and NO were 0.52 and 0.04 mg N/mg N removed, respectively. Nevertheless, the generated NO and N_2O were only respectively 0.18 and 0.02 mg N/mg N removed when sludge fermentation liquid was added. Apparently, the use of sludge fermentation liquid not only significantly enhanced nitrogen and phosphorus removal, but remarkably decreased the emission of NO and N_2O during municipal wastewater treated by anaerobic-low DO process.

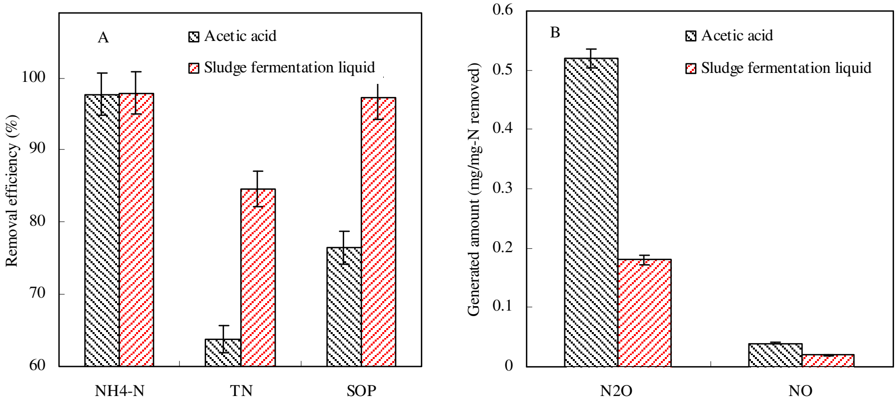

Figure 1: Comparison of the addition of acetic acid and sludge fermentation liquid to municipal wastewater on nutrient removal (A) and NO and N_2O generation (B)

Mechanism for sludge fermentation liquid increasing biological nutrient removal and decreasing NO and N_2O generation

Several factors, such as temperature, SRT, DO, have been observed in literature to influence BNR performance and N_2O generation during biological wastewater treatment. In this study these parameters were almost identical in two SBRs (temperature 21 ^{o}C, DO 0.15 - 0.50 mg/L and SRT around 22 d). Nitrite and pH have also been reported to affect N_2O generation. In the current study, two SBRs had almost the same pH variation during one cycle (data not shown). It was also found that nitrite was accumulated in two reactors in the low DO stage, but its concentration in SBR-MF was lower than that in SBR-MA. Nitrite was reported to inhibit the reduction of nitrous oxide by forming nitrous acid, which caused the accumulation of nitrous oxide in denitrification process (Zhou et al., 2008). Thus, lower N_2O and NO generation was observed in SBR-MF.

Wastewater carbon source has been reported to influence denitrification process. Acetic and propionic acids, protein and carbohydrate were the main organic components of sludge fermentation liquid in the current study. According to the batch tests in Figure 2 it can be seen that the presence of propionic acid increased nitrogen and phosphorus removal and significantly reduced the generation of both N_2O and NO, but further addition of protein or carbohydrate did not result in more N_2O and NO reduction. Propionic acid has been reported to be a more preferred carbon source for BNR microbes (Zhang et al., 2008). Also, most of wastewater carbon sources in two reactors were consumed by the end of anaerobic stage and stored as PHA. As propionic acid synthesized more PHV and less PHB than acetic acid (Zhang et al., 2008), there was greater PHV but lower PHB in SBR-MF biomass compared with SBR-MA accumulated at the end of anaerobic stage (data not shown). It has been reported that the use of endogenous carbon source PHB, compared with external acetate, as the electron donor of denitrification can cause nitrous oxide accumulation (Beun et al., 2002). Perhaps PHA with higher PHV proportion was a better endogenous carbon source for denitrification than that with lower PHV, which resulted in lower generation of both N_2O and NO in SBR-MF than SBR-MA.

Nitrous oxide reductase is an enzyme catalyzing the final step of bacterial denitrification (i.e., reducing N_2O to N_2). In its crystal structure there is a catalytic site called Cu_Z, which comprises four copper ions. It was reported that the lack of Cu^{2+} caused the accumulation of N_2O during denitrification (Granger and Ward, 2003). In this study, the initial Cu^{2+} in SBR-MA and SBR-MF were 0.00375 (calculated data) and 0.01 mg/L, respectively. As seen from Figure 2, Cu^{2+} of 0.01 mg/L significantly reduced N_2O generation compared with 0.00375 mg/L Cu^{2+}. Therefore, the presence of a certain amount of Cu^{2+} in fermentation liquid was another important reason for the lower nitrous oxide generation in SBR-MF.

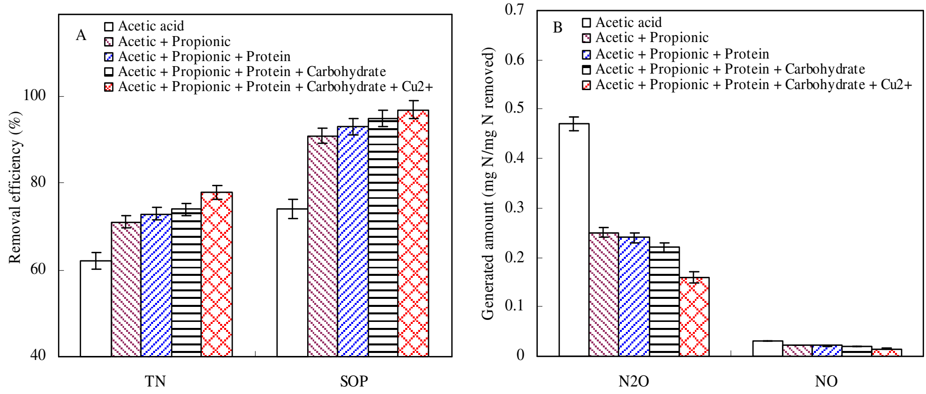

Figure 2. Effect of main organic component and Cu^{2+} in sludge fermentation liquid on nutrient removal (A) and NO and N_2O generation (B) in batch tests.

NO and N_2O accumulations are relevant to the ratios of nitrite reduction rate to nitric oxide reduction rate, and nitric oxide reduction rate to nitrous oxide reduction rate, respectively. In this study SBR-MF had lower ratios of nitrite reductase activity to NO reductase activity (N1/N2) and NO reductase activity to N_2O reductase activity (N2/N3) than SBR-MA (1.18 versus 1.30, and 3.83 against 5.41), which was consistent with the lower N_2O and NO generation in SBR-MF. In addition, the nosZ copies density in SBR-MF was 1.23×10^7 copies/g MLVSS, whereas the nosZ gene copies density in SBR-MA was 5.91×10^6 copies/g MLVSS. It was reported that higher density of nosZ gene copies was correspondence with more bacteria capable of reducing N_2O to N_2 (Amann et al., 1995). Therefore much lower nitrous oxide was observed in SBR-MF.

4 Conclusions

It was found from this study that the use of sludge fermentation liquid as additional carbon source increased BNR performance and decreased N_2O and NO emission when municipal wastewater was treated by anaerobic-aerobic (low DO level) process. The presences of Cu^{2+} and propionic acid in fermentation liquid were observed to play an important role. The analysis of denitrifying enzyme activities suggested that sludge fermentation liquid caused a significant decrease of both nitrite reductase activity to NO reductase activity ratio and NO reductase activity to N_2O reductase activity ratio, which resulted in the lower generation of NO and N_2O. The use of fermentation liquid also increased the number of bacteria capable of reducing N_2O to N_2.

Acknowledgements

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Long-term strategies for micropollutants

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1 Introduction

Discussions in the context of the climate change mostly focus on the quantity of available water resources for all mankind. The water's quality, though, is receiving far less attention although a high purity of water (chemically as well as microbiologically) is as important as the available quantity for mankind. This doesn't only apply for its use as food, but also for its industrial use in the context of the production of high technology products for which high-purity water is often needed.

2 Micropollution in the aquatic environment

Micropollutants are chemicals in the aquatic utilization cycle in concentrations of µg/L or below (Schwarzenbach et al. 2008, Kümmerer 2010). Currently in this context organic chemicals are basically considered as such. This includes ingredients of detergents and cleaning materials, paints, flame retardants and other chemicals being washed out from textiles, pharmaceuticals, disinfectants, biocides, corrosion inhibitors, complexing agents, softening agents, preservatives, to name but a few of the most common ones (Fatta-Kassinos et al. 2010, Kümmerer 2011). Depending on their usage, these originate from households, trades, industry, healthcare, agriculture and other sources. About 30,000 of the products on the EU-market are considered to be environmentally relevant. A further increase of the products' and chemicals' diversity is expected (UNEP 2013). At the same time, the re-use of purified sewage gains more and more importance due to an aggravating water shortage, e. g. for food production (Fatta-Kassinos et al. 2015).

A lot of these materials are released into the environment as an “unwanted” side-effect by their intended use. Improved possibilities of chemical analytics helped to make that concentration level accessible during the last one or two decades. Not just the detection limits were improved but also the list of principally accessible chemicals was expanded. Notably polar compounds may nowadays be determined in a much better and extensive way than 20 years ago.

At best, micropollutants are unwanted substances in the water. However, there are cases in which such substances already have negative impacts on environmental organisms at quite low concentrations. Regarding human-beings there is hardly any data available on this issue. On the one hand this is due to the fact that the concentrations are so low and on the other hand it is due to the great time scales and different life conditions which hardly allow an establishment of an exact cause-and-effect relationship for chronical and sub-chronical effects or for causing cancer. However, the properties of some of these substances, as for example those directly interacting with the DNA (e. g. several cytostatic drugs) or endocrines, cause to take notice. For the time being all risk assessment is based on isolated considerations of single substances. The fate of substance mixtures still is very vague (EU 2014).

In terms of preventative health care as well as of sustainable development, micropollutants represent a major obstacle to a sustainable water management. This doesn't only apply to the usage of water as food and the protection of the environment, but also to the industrial usage of water. The increasing progress in some fields requires increasingly more pure water. Such a purification of water, though, demands energetic and technical efforts, thus also financial efforts. All these points suggest preventative measures in our region as well.

3 Limits of (advanced) waste water and drinking water treatment

The processing of water to drinking water as well as the purification of waste water represent one of the major progresses during the past 100 years, to which we probably much more owe the higher life expectancy than to all other medical processes – apart from the development of antibiotics maybe.

Not least because of processes in the water and waste water treatment along with a very much improved handling of waste and chemical products as a whole, the concentration of chemical substances in the aquatic environment and the aquatic utilization cycle as so-called micropollutants (also called “trace substances”) is quite low nowadays but still present to a considerable extent in most parts of Europe, North America and Australia. For this reason attempts are being made to further improve the water quality in order to completely eliminate trace substances – mostly with the focus on waste water purification and drinking water treatment, so to say at the end of the pipe. However, it has also been revealed in the past few years that due to the high amount of chemical substances with totally different properties and areas of application, the limits have been reached. With regard to the standard waste water treatment, for instance, a prolonged sludge age doesn't lead or only for some chemicals leads to an improved elimination of the micropollutants. In some cases the elimination of the precursors (i.e. parent chemicals) is improved but if the elimination isn't based on sorption (i.e. accumulation in activated sludge) or complete mineralization, new, mostly unknown substances, i.e. unknown products of incomplete biodegradation (so-called transformation products) are created, and as a result of microbiological processes mostly also with a change in their chemical structure (Längin et al. 2008, Kümmerer 2011, Trautwein et al. 2014, Lampropoluou and Nottel 2014). These have different physical-chemical properties resulting in a different environmental behavior and different effects.

As a consequence of the very unsatisfactory elimination of chemical substances in waste water, the research on techniques of advanced waste water treatment has been intensified considerably over the past years and has partially (e. g. Switzerland) been implemented on a large scale. Numerous investigations, mostly on pharmaceuticals, have revealed, though, that neither the single techniques (e.g. sorption on activated carbon, membrane and other filtration processes, oxidation processes with strong oxidants like for example ozone and/or hydrogen peroxide or photolysis (treatment with UV radiation) nor their possible combinations eliminate all those micropollutants with respect to amount and concentration). In general a combination of techniques may eliminate a few substances at a rate of 80 to 100 percent (and probably only a minor part will then also be fully mineralized), another amount at a rate of 50 or 60 percent and depending on the technique and the substance combination a more or less bigger part will not be eliminated at all. This is easily comprehensible as different chemical substances also have different chemical properties such as polarity, functional groups that can interact with a specific sorbent or can react with a specific reagent such as ozone as otherwise they wouldn't be different chemicals with different (application) properties in the first place. This also applies for substances within a comparatively closely related substance group as for example certain non-ionic surfactants or flame retardants or even subgroups of pharmaceuticals, respectively component groups of them like antibiotics. Even substances within the group of the ß-lactam antibiotics, of which the molecules are quite similar, may have different properties and fates. Especially as far as oxidative processes are concerned, a variety of transformation products with unknown properties is often created (Nödler et al. 2013) – depending on the technique up to ten or more from one parent substance. These and their individual relative share may differ a lot depending on the chosen reaction conditions and treatment duration and may be subject to temporal dynamics. As these compounds are often not available as pure substances it cannot be assessed whether a high peak in UV-Vis detection or mass spectrometry also corresponds to a high concentration and vice versa – let alone their toxicity. Furthermore, their relative share is dependent of the time of treatment (Garcia-Käufer et al. 2012). Therefore the appropriate treatment as well as the optimal duration is different for each substance. It is therefore no surprise that in the literature (Haddad et al., in press) there had already been described 38 transformation products for the antibiotic ciprofloxacin up until May 2012 alone. It has to be noticed that this doesn't mean that all those created could be identified as it cannot be said which are accessible to those analytical methods and which are not, which is due to a lack of reference substances. Moreover, the establishment of a safe chemical structure is associated with high uncertainty. It has also been revealed that there might be an increase in toxicity resulting from such a treatment (Garcia-Käufer et al. 2012, Illes et al. 2014, López-Serna et al. 2014), including the drinking water treatment (Schmidt and Brauch 2008). Latest research suggests that the ozonation of waste water may even lead to a selection or accumulation of resistance material in the pipe.

In literature the unproven assumption can be found that for instance transformation products being created in oxidative treatments generally had a better biodegradability because of the introduction of hydroxyl groups into the parent molecule. However, a higher polarity doesn't necessarily imply a better biodegradability. Biodegradability is determined by the fact that a molecule fits into the corresponding enzyme's "pocket" of its active center" and may interact with it (not too weakly, not too strongly, fitting spatial arrangement). Accordingly, in literature more and more cases are being reported in which transformation products being created in oxidative treatments do not have a better biodegradability than their parent substance. It might be that those transformation products are better absorbed on suitable surfaces. Activated carbon for example is rather a good sorbent for less-polar substances. If a biofilm is being formed on the activated carbon after a certain time, this is slightly more polar and some substances may absorb there. To which extent this will occur, though, is yet uncertain. In this context the question remains unexplained what this means for a potential evolution of resistance if also antibiotics are accumulated in such biofilms. And what's the use of activated carbon as a sorbent in the case of biofilm cultivation? Wouldn't the slow sand filter be just as suitable? Some investigations show at least that slow sand filters reach the best elimination capacities and that in comparison they have the best life cycle assessment (Jones et al. 2007).

Given the fact that in Germany alone several thousand to ten thousand different parent substances are considered to be environmentally relevant, complete elimination and prevention respectively identification and assessment of the transformation products at the end of the pipe de facto represents an insoluble task, even though this might not appear to be the case at first glance since certain substances can in fact be eliminated by the (advanced) waste water treatment. In fact, for most substances we don't have any data regarding their elimination and degradation behavior or even their effect (with up to one hundred possible endpoints that would have to be measured) and with regard to the variety and all potential transformation products this will probably never be possible in a cost-effective manner, if at all.

Moreover, we neither know yet which new substances might appear on the market in future and which will be released into the aquatic cycle, nor how these will behave in the different cleaning technologies. The example of pharmaceuticals shows that up to now most investigations have been made on so-called "traditional" substances which partially don't have such a great significance any more or which have meanwhile been replaced or are about to be replaced by new ones. As far as brand new substance groups such a nanoparticles are concerned, we are facing enormous methodical challenges. Moreover, it is completely uncertain which chemical entities we will have to expect in future. The same applies to all other substance classes and application areas, although the dynamic might not be as high as in the case of nanoparticles. As a result of the increasing usage of high technology metals, as for example those from the rare earths group, for products for the turnaround in energy policy ("Energiewende") or medical application, it can be expected that these will also be increasingly released into the water cycle. First indications (e.g. Gadolinium or Dysprosium) already exist (Kulaksiz and Bau 2011). Gadolinium is meanwhile being used as a hydrological tracer for anthropogenic influences (Möller et al. 2000). It is yet unknown whether highly toxic substances such as Gadolinium (III) or Chrome (VI) arise in oxidative methods of the water purification and the waste water treatment. At any rate they are not completely eliminated in sewage plants. This is why trace substances and their transformation products are considered to be a worldwide issue (Rockström et al. 2009).

4 Long-term strategies

Undoubtedly the conventional waste water treatment has highly contributed to the progress in health and environmental protection. As outlined above, though, it cannot offer a solution to the problems to such an extent as it would be needed (including the advanced treatment; 4th stage). New approaches are necessary which not only focus on the end of the pipe but also consider other ways of use and fate of chemical substances in the aquatic cycle in an interdisciplinary context. Such an approach at the beginning of the pipe, i.e. focusing on the chemical substances and the reason for their usage, has the charm that the focus is on prevention rather than on (incomplete) treatment that needs additional resources and may create follow-up problems. Hence, with regard to substances a much more sustainable water management becomes possible also where the different preconditions for purely technical approaches do not exist and may not be established, e.g. in developing and/or arid countries. There won't be the one and only strategy or even technology but (partly) rather a variety of appropriate measures or set of measures depending on the nature, the type as well as on the reasons for the use of chemical substances (their features and functionalities).

The measures listed below may be considered as possible approaches – by no means exhaustive. Some may rather be implemented on an operational basis, others rather on local or regional catchment area, while some even require political and social rethinking and will therefore take more time:

Improvement of separation of waste water streams and application of a better-targeted treatment and/or retain pollutants.

Applying more substances in closed systems, especially problematic ones (those that are not mineralized quickly and completely after being released into the aquatic utilization cycle or the aquatic environment).

Using chemical substances that are easily mineralized, i.e. quickly and completely, in conventional sewage plants and in the aquatic environment.

Development of substances with an improved/optimized biodegradation level ("Benign by Design", Kümmerer 2007, Rastogi et al. 2014, 2015) for products that may be released in the waste water for unintended or even intended use (e.g. personal care products and cosmetics, household chemicals, biocides including pesticides, disinfectants and pharmaceuticals).

Considering the elimination of pollutants in drinking water treatments as a "police filter" rather than as a routine, i.e. it should only be used as a safety barrier in case such a pollutant really gets there.

Considering the entire material flows for the same substance in different applications, e. g. within one industrial state not just a single company

Going beyond individual applications, i.e. focus on the entire material flows (local, regional, national level) and depending on their level not just on individual companies or branches as well as their temporal variations and dynamics.

Reducing all in all the variety of substances and their temporal dynamics in different applications.

Keeping an eye on the entire flows (as well as on all sources of a substance, creating balance sheets) and creating them as homogenous as possible as well as keeping any impacts to a minimum.

Attaining a better knowledge about the specific reasons for the usage of certain substances in industry, commerce, agriculture, households, healthcare facilities e. a.

Subsequently achieving the overall objective: a better knowledge about the functionality certain substances offer for their application.

Clarification of non-material alternatives (e.g. different production methods, different product, different values) which makes application of certain substances redundant, along with savings potential for producers and end users.

Development of new business models: for instance in the case of disinfectants, the objective would not be the highest possible consumption but rather the maintenance of certain standards of hygiene – disinfectant manufacturer can deliver both, in the latter they would have an interest in applying disinfectants only where actually necessary and/or if training measures are not successful. If they need less disinfectants at equally high standards of hygiene, they safe i. a. commodity costs and generate a higher share of the turnover by non-material resources as for example user trainings and consultation (Streek et al. 2011).

In macroeconomic terms (economically and financially) a slight improvement within the production process may cause significant extra costs for the waste water and drinking water management (higher costs, higher toxicity); possibly with allocation of external costs and in the worst case it is better to stick to the "old" substance not being subject to such hygienic and monetary consequences or which allows a much better estimation of risks thanks to data being available ("substitute problem").

Adequate consideration of the precautionary approach: "If there is nothing to be seen, it doesn't mean there is nothing/that nothing happens", and an adequate dealing with agnosia or impossible knowledge (e. g. primary elimination doesn't necessarily imply full mineralization or improvement of the situation), long-term risks are beyond a classical cause-effect analysis.

As already outlined above, this list is not exhaustive and some facts aren't new like the one that avoidance is better than reduction only or even treatment of substances being released in the aquatic utilization cycle or the aquatic environment. It is important, though, not to consider only one approach but rather all options. On the one hand a situation-specific application is essential, on the other hand it should not be too restrictive.

According to the principle of "Ockham's Razor", the solution should finally be as simple as possible and as complex as needed only. If the entry of chemical substances regarding their nature, amount and spatio-temporal dynamics is considerably reduced, the waste water treatment – as one building block of several - can better fulfill the requirements. This view may indeed not be new, but it holds a still un-lifted treasure!

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Overview and results from disinfection trials at WWTP Steinhof e

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Abstract

The secondary effluent of WWTP Brunswick is currently used for irrigation or is discharged into a meander system. The water quality can be attributed to water class 4 according to DIN 19650 . In order to achieve a higher water quality class allowing further reuse applications a disinfection step is necessary. The outcomes of a quantitative microbiological risk analysis (QMRA) carried out during the research project CoDiGreen (Seis 2012) suggested that a further reduction of Noro- and Rotaviruses by 1.5 log is necessary to reduce the risk for field workers as defined by the WHO. The goals of the presented trials were to define the doses achieving the water class 3 (E. Coli 2000 MPN/100 mL, Enterococci 400 MPN/100 mL).

1 Piloting Brunswick

Physical and chemical parameters

The WWTP Brunswick is designed for 200.000 p.e. and equipped with biological phosphorus removal and pre-denitrification. Four secondary clarifiers are operated and primary and excess sludge is digested separately. The secondary effluent is used for irrigation either at the nearby meander for polishing or at local farms enhancing yields due to water and nutrient supply.

During the pilot trials in autumn 2014 an intensive monitoring campaign was carried out. Following methods were used:

- pH-value	DIN EN 38404 C5
- conductivity	DIN EN 27888 C8
- COD, filtered	DIN ISO 15705 H45
- COD homogenized	DIN ISO 15705 H45

- DOC DIN EN 1484 H3
- Suspended Solids DIN EN 872 H33
- AOX DIN EN 1485 H14

Beside one sludge run-off incident the secondary effluent quality was stable and within the expected range.

Table 3: Summary of physico-chemical parameters of WWTP Brunswick

Parameter	Unit	Min	Max	Median	N
T	°C	15.2	21.0	**18.1**	58
pH	-	6.3	7.7	**7.3**	58
Turbidity	NTU	1.9	537	**3.6**	58
Suspended Solids	mg/L	1.0	770.0	**6.2**	58
Transmittance	%	45.0	53.9	**50.5**	31

Microbiological parameters

The direct measurement of viruses is still timely and cost intensive, so the following widely accepted indicator organisms were chosen: E.coli, E.cocci, Clostridium Perfringens, and somatic coliphages. A correlation between the indicator organisms and the pathogens was calculated based on data published by Hijnen et al. (2006). With this correlation the following LUR for UV disinfection were assumed to be equivalent to 1.5 LUR of rotaviruses:

Table 4: Target LUR of indicator organisms assumed to be equivalent to 1.5 LUR of viruses

Indicator organism	Target LUR
E.coli	3.17 LUR
E.cocci	1.77 LUR
Clostridium Perfringens	0.32 LUR

Considering that norovirus is more sensible to UV radiation than rotavirus it is assumed that achieving the 1.5 LUR for rotavirus means consequently an equal or higher removal for norovirus (Hijnen et al. 2006).

The results presented hereafter for the pilot scale trials at WWTP Brunswick were gathered and evaluated within his Bachelor program by Reichelt (2015).

Table 5: Measured microbiological parameters

Indicator organism	Indicator for	Method
E.Coli	bacteria of faecal sources	Colilert-18/Quanti-Tray;H
E.Cocci	faecal streptococcus group	DIN EN ISO 7899-2;H
Clostridium Perfringens	Spore forming anaerobic-persistent bacteria	DIN EN 26461-2;H
Somatic Coliphages	Indicator for enteric viruses	DIN EN ISO 10705-2 As explained by Gnirrs et al. (2015)

Grab samples were taken 3 – 5 times a week and Figure 4 summarizes the results.

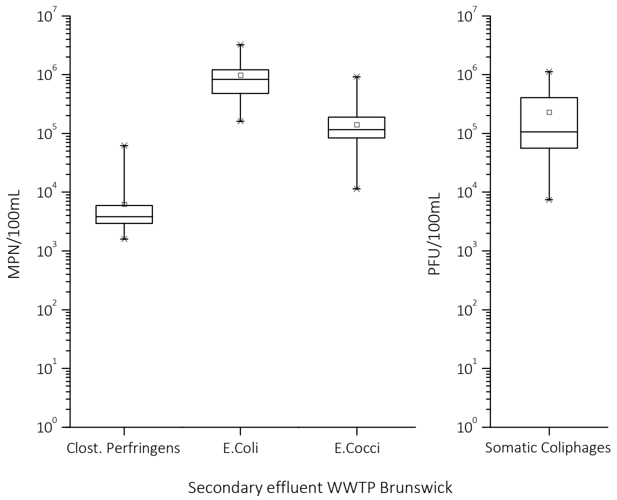

Figure 4: Pathogens present in secondary effluent WWTP Brunswick – Samples taken during pilot testing Sept. – Nov. 2014

2 Set up pilot plants

Ultraviolet radiation

The UV disinfection reactor (LBX 10, Xylem-Wedeco) was designed for a maximum flow of 15 m3/h. During the trials a flow between 5 and 8.1 m3/h was tested. Equipped with wipers for mechanical cleaning this system is suitable for secondary effluent. The wipers frequency was set to once per hour. The three low-pressure UV-C lamps were operated approximately for one year prior to the presented investigations, so the disinfection results can be assumed as representative in terms of lamp ageing.

Figure 5 shows the basic flow sheet for the UV disinfection plant.

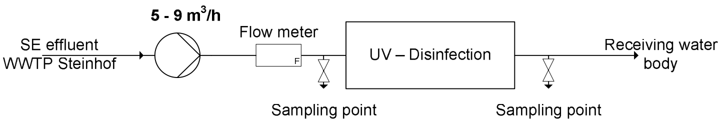

Figure 5: Basic flow sheet UV disinfection

UV lamps cannot be controlled individually in term of power output, therefore the fluence respectively the specific energy consumption is set by controlling the flow, see

Table 6. Within in the first trial phase three specific energy consumptions were tested: 27, 32 and 44 Wh/m^3. After a first evaluation of the disinfection results with respect to the defined goals a specific energy consumption of 35 Wh/m^3 was recommended.

Table 6: Flow and correspondent specific energy consumption and fluence

Flow in m^3/h	Dose equivalent in J/m^2	Specific energy consumption in Wh/m^3
8.1	500	27
7	600	32
6.3	650	35
5	800	44

Performic acid (PFA)

The pilot plant to produce performic acid on site (Kemira, DesinFix) was designed with a flow proportional dosing system,. The pilot scale installation was designed for a water flow of 50 – 100 m^3/h and a dosing range of 0.5 to 3 ppm PFA. A 20 m^3 reactor was used to maintain a retention time of 10 – 20 min, see Figure 6.

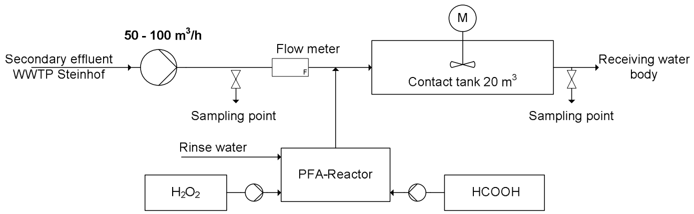

Figure 6: Basic flow sheet PFA pilot plant WWTP Brunswick

During the trial period in 2014 the flow was kept constant at 50 m^3/h whereas three concentrations of PFA were tested: 1.4, 2.0 and 2.7 ppm. The outcomes of the first trial phase were used to conclude the following statements:

- UV and PFA show similar effectiveness on indicator organisms
    - ➢ Target LUR of 1.77 for E.cocci is also valid for PFA

Therefore a PFA dose of 2 ppm is recommended for the goal of 1.5 LUR of rotavirus.

3 Results pilot scale investigations

In order to allow a complete data evaluation the data is presented in total, including the first trial phase and the results obtained with the recommended doses.

Figure 7 and Figure 8 show the disinfection capacity on E.coli for both pilot plants. The different specific energy demand, respectively PFA dose are indicated and the mean LURs are given. The mean LURs are calculated using the LUR of each data pair. E.coli is known to be sensitive to UV radiation what is clearly shown in Figure 7.

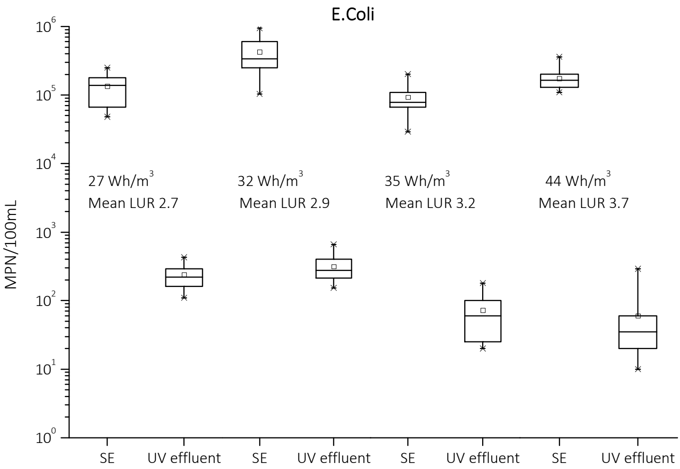

Figure 7: Disinfection results - E.coli - UV radiation

The LUR rises from 2.7 to 3.7 by increasing the specific energy consumption from 27 to 44 Wh/m^3. With respect to the targeted LUR of 3.17 for E.coli the recommendation is a specific energy consumption of 35 Wh/m^3.

For the PFA a similar result was obtained, a clear sensibility of E.coli to the disinfection agent, see Figure 8. The higher the dose is the higher the LUR is. But the goal of 3.17 LUR was not achieved, in contrast to the assumption that a similar sensitivity correlation between E.coli and viruses for UV and PFA exists. During the trials it was shown that the minimal retention time after dosing was significantly below the targeted 10 min.

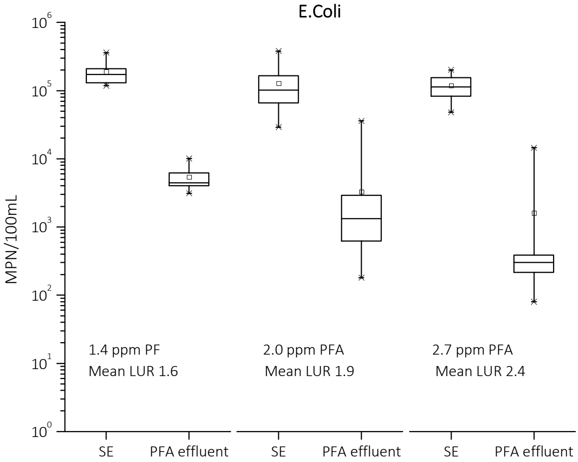

Figure 8: Disinfection results - E.coli – Performic acid (PFA)

The targeted LUR of 1.77 for E.cocci was achieved even with a lower specific energy consumption of 32 Wh/m^3, see Figure 9. Nonetheless, the maximum concentration exceeded 100 organisms/100mL as required by the DIN 19650 to achieve water class 2. A dose of 2.0 ppm of PFA achieved a mean LUR of 1.8 for E.cocci and is therefore higher than the targeted 1.77 LUR. The high maximum value indicated by the upper whisker points out to measurements exceeding the limit concentration.

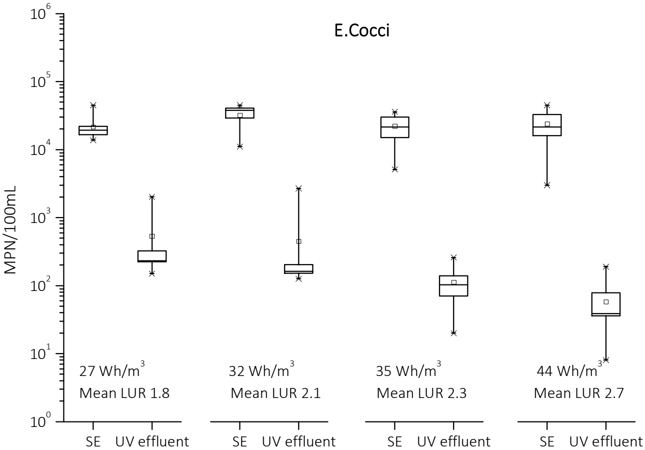

Figure 9: Disinfection results - E.cocci - UV radiation

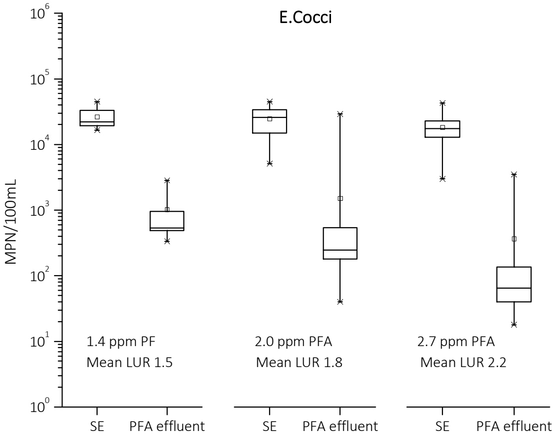

Figure 10: Disinfection results - E.cocci – Performic acid (PFA)

For Clostridium Perfringens low LURs for both treatment technologies and all doses tested were found. The LUR was < 0.5 log (see also Gnirrs et al. (2015)).

Somatic Coliphages show a high sensitivity to UV radiation and the LUR applying 27 Wh/m^3 was > 3. Increasing the specific energy consumption further led to LURs above 4.0. Only the LUR for the highest specific energy consumption decreased in comparison, which can be explained by the already high LURs. In this case the mean value is biased by the maximum value.

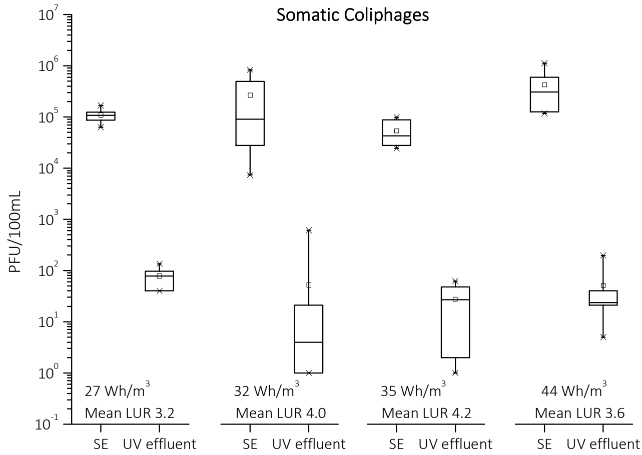

Figure 11: Disinfection results - Somatic Coliphages - UV radiation

As shown in Figure 12 PFA is effective against somatic coliphage. But increasing the dose from 1.4 to 2.7 ppm does not increase the LUR to the same extent. In this case the indicator organism somatic coliphages does not show similar sensitivities for UV and PFA. Nonetheless a LUR > 2.0 can be satisfying for water reuse applications where partial disinfection is sufficient.

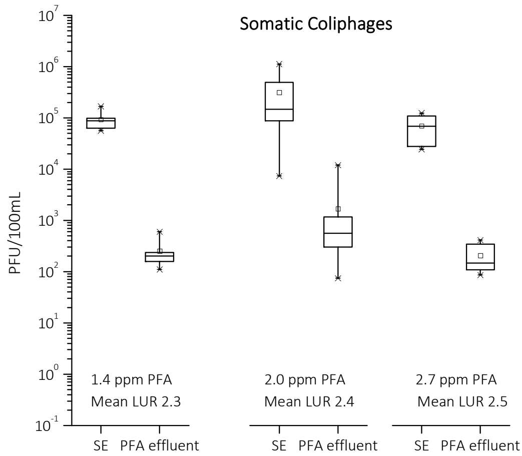

Figure 12: Disinfection results - Somatic Coliphages - Performic acid (PFA)

Retention time PFA reactor

A minimum retention time of 10 min is recommended for the PFA reaction by the supplier. Therefore a contact tank with 20 m^3 was installed for piloting. The design with a length to height ratio of 2.5 was thought to lead to an almost plug flow. Even though the piping was designed in order to maintain and control the water level in the tank, thus the theoretical reaction volume, the position of the connections would have led to a constant short circuit. Therefore a mixer was installed in the middle of the tank, supposed to lead the water flow to the top of the reactor and increasing the mean retention time. Nonetheless, the mixer was more effective than expected and tracer tests were performed implying a minimum retention of 3.4 min and long tail indicating higher retention times.

In order to evaluate the impact of this reduced reaction time, several sampling were performed without quenching the residual performic acid with Sodiumthiosulfate STS. Considering the time for storage and transportation to the laboratory, a complete reaction can be assumed representing an ideal designed reaction basin. Additionally samples with the quenching reactant were taken in parallel enabling a direct comparison. Figure 13 shows the mean removal results for E.coli, E.cocci and Clostridium Perfringens with and without quenching. The results prove that the former presented results underestimate the disinfection performance for the PFA. Table 7 compares the median LURs with and without quenching.

Bearing this in mind, the recommendation dose of 2.0 ppm for WWTP Brunswick can be considered sufficient. The impact of the dose on the economic evaluation will be discussed in section *economic evaluation* when different dosage and energy costs are evaluated.

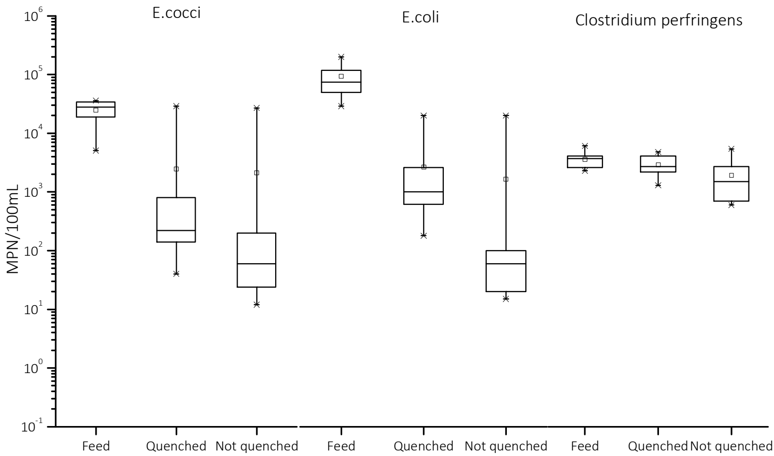

Figure 13: Comparison results for 2 ppm PFA - with and without quenching

Due to the maximum value obtained during this measurement campaign the mean values lies for all three indicator organisms in the same range. Nonetheless, the median is clearly lower for samples not quenched for E.coli and E.cocci. This backs the assumptions that the reaction was not completed. The maximum values indicate samples when only a very low disinfection performance was achieved with PFA. These outliers could not be explained by operational issues and an explanation for these findings is still missing.

Table 7: Comparison of median LURs with and without quenching

	E.coli	E.cocci	Clostridium Perfringens
With quenching	1.95	2.02	0.08
Without quenching	3.06	2.62	0.46

Summary Pilot trials WWTP Brunswick

After piloting for three months testing four different microbiologic parameters with 3 – 4, doses the disinfection performance for UV radiation and performic acid can be compared for WWTP Brunswick. Considering the impact of the retention time for the reaction with performic acid, 2 ppm PFA and 35 Wh/m^3 is the recommendation in order to increase the water class from 3 to 2, according to DIN 19650. Gnirrs et al. (2015) stated that other viral parameters (e.g. F+ bacteriophages and Norovirus) are less sensitive against PFA compared to the somatic coliphages or bacterial indicators. Thus to validate the removal of pathogenic viruses by PFA more research is required.

The correspondent LURs are given in Table 8. These dosages proved to be sufficient as mean/median values, but run-away values, caused by sludge run-off, lead to high values and based on the grab sample value the disinfection result is not appropriate. Therefore it has to be kept in mind, that different the regulations might require different sampling procedures and different quantification of limit values. E.g. either median values or 90 % of all measured values.

Table 8: Comparison disinfection results Brunswick – Mean LURs

Parameter	UV 27 Wh/m^3	UV 32 Wh/m^3	UV 35 Wh/m^3	UV 44 Wh/m^3	PFA 1.4 ppm	PFA 2.0 ppm	PFA 2.0 ppm*	PFA 2.7 ppm
E.coli	2.7	2.9	**3.2**	3.7	1.6	1.9	**3.1**	2.4
E.cocci	1.8	2.1	**2.3**	2.7	1.5	1.8	**2.6**	2.2
Clostridium Perfringens	0.4	0.5	**0.4**	0.4	0.1	0.2	**0.5**	0.3
Somatic coliphages	3.2	4.0	**4.2**	3.6	2.3	2.4		2.5

*Without quenching (median)

4 Economic evaluation

An economic evaluation with regards to the disinfection level and necessary reduction of indicator organisms is presented in the coming sections. The presented results were in parts gathered by Graß (2015) during his Bachelor program.

Six set-ups are compared with changing assumptions for water flow, energy costs and chemical doses:

1.	Ultraviolet radiation as a single line	UV
2.	Ultraviolet radiation in a redundant set-up	UV (n+1)
3.	Performic acid as a single line	PFA
4.	Performic acid in a redundant set-up	PFA (n+1)
5.	Ultraviolet radiation and performic acid as a back-up	UV + PFA
6.	Chlorination with ClO_2 in a redundant set-up	ClO_2 (n+1)

The net present value helps to compare different options considering investment, re-investment and operational costs over the expected lifetime and cost evolution. Since ClO_2 does not react with Ammonia this chlorination agent was chosen for this economic evaluation. It has to be noted, that chlorination was not tested during the pilot scale trials and the concentration values given are recommendations provided by a supplier. It has to be noted that chlorination is due to AOX formation not discussed for wastewater disinfection in Germany.

Following assumptions were chosen to start with the cost estimation and kept constant, whereas other factors are varied in order to show the sensibility of the disinfection step:

- Rate of interest: 3 %
- Planning costs 18 %
- Life time of construction: 30 years
- Lifetime of machinery: 12years
- Lifetime of electric equipment: 10 years
- Lifetime of UV lamps: 3 years
- Peak flow: 0.65 m^3/s
- Evaluation over 30 years

Costs for UV radiation can be assumed to be strongly dependent on investment costs, whereas performic acid and chlorination are affected by operational costs. These different dependencies can be best compared by calculating the net present value. Figure 14 shows the results when a total of 11 mio m^3 of water is disinfected per year. The recommended doses of 2 ppm PFA, 35 Wh/m^3 and 2.0 g/m^3 ClO_2 were used for design and operational cost constraints. An energy price of 0.12 €/kWh has been given by WWTP Brunswick as the current energy price. WWT Brunswick has a high production of biogas due to the co-fermentation of energy plants. Efficient heat-and-power stations help to reduce the energy costs.

The different nature of the disinfection technologies is shown by the intersection of the graphs. Even though 4 times higher investment costs are required for the UV (n+1) set up compared to PFA (n+1), after 10 years the lower operational costs pay off and the UV disinfection is favourable. Over 30 years, a benefit of 0.9 mio € is accumulated comparing the redundant set ups. ClO_2 it is the most economical alternative with a net present value of 4.83 mio €, comparing the redundant set-ups only.

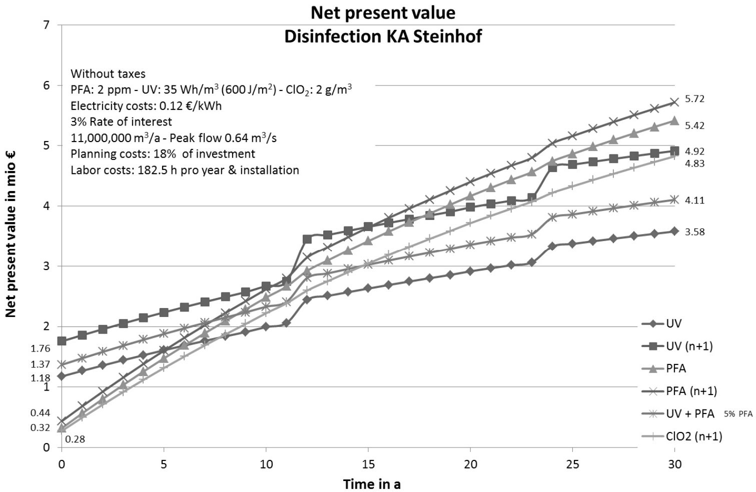

Figure 14: **Net present value for different disinfection technologies at WWTP Steinhof – 11 Mio. m³/a**

Disinfection based on crop demand

The previous calculation was based on the fact that all water nowadays sent to the irrigation area has to be disinfected, which accumulates to 11 Mio. m^3 per year. Considering a theoretical crop demand of ca. 120 mm/ha the total volume needed for the 3000 ha declines to 3.6 Mio m^3 per year. Calculating the net present value with these preconditions changes the evaluation.

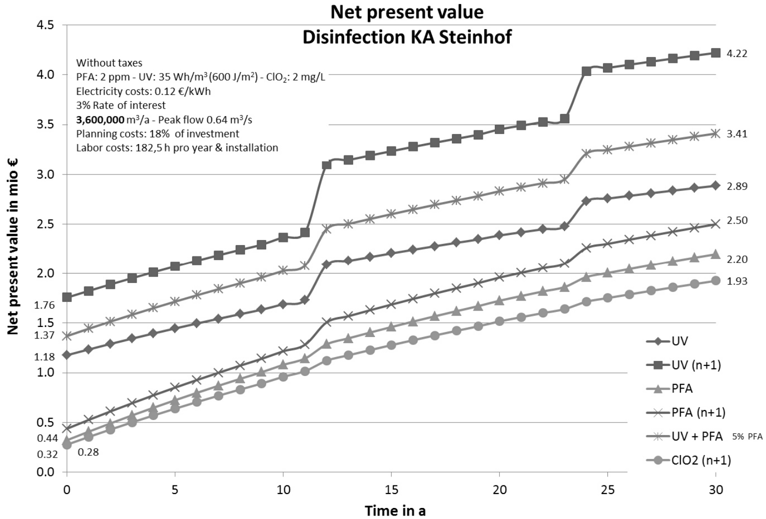

Figure 15: Net present value of different disinfection technologies at WWTP Steinhof - 3.6 Mio. m3/a

Due to the less water and therefore less chemicals required, the technologies driven by operational costs are more favorable and lowest net present value is calculated for the chlorination step with 1.93 mio €, followed by PFA in the redundant setup, 2.5 mio e, and the highest net present value is given for the UV in a redundant design with 4.22 mio €. No trade-off can be defined as the curves do not intersect for these preconditions.

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Water management in farms and potential water reuse strategies

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Abstract

Agriculture is the largest consumer of freshwater, representing more than the 70% of the total water consumption worldwide. Likewise, the increase of population will also raise the demand for food, and more water will be used to produce the needed food for an increasing population. Without improved efficiencies, agricultural water consumption is expected to increase by 20% globally by 2050 (WWAP, 2012). Reclaimed water is a potentially valuable resource for livestock farming. Properly used, reclaimed water is responsible with the environment, public and animal health and food safety. Also, it may have advantages over the use of potentially limited or costly traditional primary water sources in terms of reliability of supply and price. The main objective of this study was to explore the potential options of using reclaimed water in farming activities.

To determine the key points in which reclaimed water could be potentially used in farming activities, water inputs and outputs were described in a dairy cow farm (SAT Sant Mer, Sant Esteve de Guialbes, Girona, Spain), a fattening pig unit (Alfès, Lleida, Spain), and a broiler unit (Empuriabrava, Girona, Spain).

In the evaluated farms, most part of the water was consumed for livestock drinking purposes (from 70 to 96% of total farm water consumption). Therefore, the use of reclaimed water for direct consumption by livestock, seems the most promising water reuse option.

In conclusion, in livestock activities the main use of water is for animal drinking purposes. Therefore, establishing strategies to potentially use reclaimed water from treatment plants or recycling the own wastewater generated in the farms for animal drinking are the key points to reduce the use of water in farming activities. Membrane filtration followed by a disinfection step could be a good methodology to improve the quality of wastewater and use it for livestock drinking purposes or cleaning usages.

1 Introduction

From the United Nations World Water Development Report 2014, it is highlighted the increasing demand of water around the world, because of the growing demands from manufacturing, thermal electricity generation and domestic use. Due to the pressure exerted on water resources, it is necessary to develop systems and improve practices over time to reach the quality required for each use along with preserving natural resources. Poor or unsuitable water quality often further reduces availability, restricts uses, and increases the costs of supply. Regions with low rainfall and high population density are prone to water stress as well as areas with intense agricultural, industrial or tourism activities. Global climate change is already exacerbating these problems with projections indicating significant and widespread impacts over the medium to long term. These developments will inevitably lead to growing competition between different water users, with high quality resources being protected and reserved for drinking water production.

In this sense, the agrarian uses, including agricultural irrigation and livestock consumption, account for more than the 70% of the total water consumption worldwide and thus, direct water reuse for the mentioned purposes has special interest. Reclaimed water is a potentially valuable resource for the livestock farming. Properly used, reclaimed water is protective with the environment, public and animal health and food safety, and may also have advantages over the use of potentially limited or costly traditional primary water sources in terms of reliability of supply and price.

In EU reclaimed water is not used for livestock drinking purposes. However, it is worth noting the case of Australia, where reclaimed water can be used for direct consumption by livestock when meeting specific quality standard criteria. On the other hand, in the United States, de facto water reuse often occurs. In this case, there are guides regarding acceptable water quality for livestock consumption.

The objective of the present study was determining water cycles in farms, and evaluating possibilities of water reuse or using reuse water in farming practices.

2 Materials and Methods

Three livestock farms: one dairy cow (SAT Sant Mer in Sant Esteve de Guialbes, Spain), one pig fattening unit (Alfès, Lleida, Spain), and one broiler unit (Empuriabrava, Girona, Spain), were visited to describe the water cycle in their facilities. During these visits, the water cycle in the farms was evaluated. In each of these farms, total monthly water consumptions were recorded with the general water meter of the farms. Then, water entrance sources and water consuming farm activities were identified, and internal water consumptions were assessed directly with water meters, or indirectly, by estimating the time of usage and hose flow for cleaning, or by estimating water intake according to animal physiologic characteristics. Water outputs were identified and water samples were obtained at these points to evaluate the quality of the outgoing water (conductivity, pH, suspended solids, turbidity, N content, bacterial counts, COD and BOD). Finally, the farm water cycle was evaluated and the potential usages of reclaimed water or recycled water within the farm were pointed.

3 Results and Discussion

3.1 Dairy cow farm

Considering the water cycle in the dairy farm with 700 dairy cows producing 672,000 kg of milk monthly, 2,580 m^3/month of water were used. Similar values were reported in previous studies: 2.7 L/kg raw in Galicia (Spain) (Hospido et al., 2003), 3.58 L/kg of milk in Brandenburg (Germany) (Drastig et al., 2010), and 3.78 L/kg milk in US (Capper et al., 2009).

Figure 1 shows the water management strategy in the dairy farm indicating in brackets the percentages of water used in the different farm applications. The first usage was for drinking purposes (70%), followed by cleaning activities such as cleaning the milking parlor (17.6%), or the milking equipment (1.1%). During the hot season some water is used for cooling cows (4.2%), and 7.1% of the water use can be attributed to other usages such as cleaning several field or farm tools or the facilities. In this farm, the manure was split in the solid and liquid part, and the liquid part was recycled to do yard flushing. Part of the water consumed by the cows was transformed to milk (21.1%), or excreted by animals in form of urine, faeces, and sweat (46.8%). The water used for cleaning purposes finished in the manure pit (32.1%), which it was split in the liquid and solid phase by a manure separator. Part of the liquid phase was recycled for yard flushing, and the rest of liquids and solid was used to fertilize the fields. Similarly, Drastig et al. (2010) divided water used in three main blocks: 82% for drinking, 11% for milk processing, and 7% for other services such as the use of water high pressure cleaner. Regarding water quality of outputs (Table 1), it was observed that although water troughs were cleaned daily some bacterial contamination was presented on it ($1.1x10^5$ total coliform cfu/100mL), and the wastewater from cleaning the milking parlor presented high bacterial contamination ($4.6x10^8$ total coliform cfu/100mL), and high values of suspended solids (7,300 mg/L).

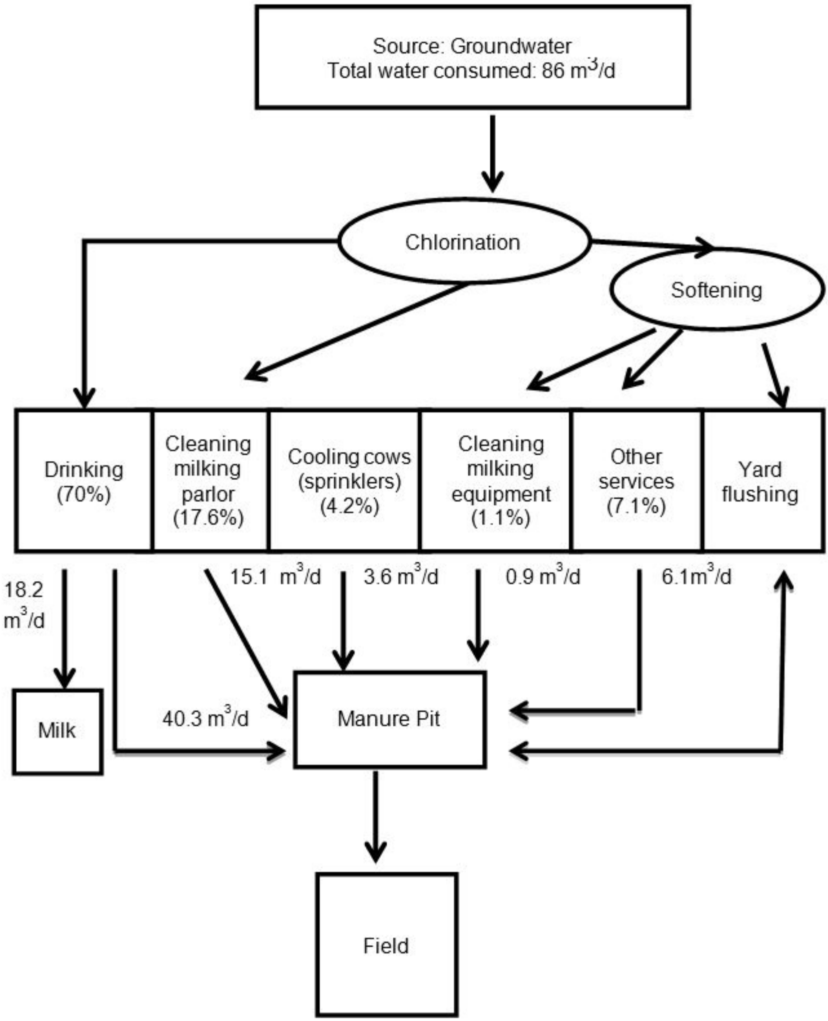

Figure 1: Diagram of water inputs, usages, and outputs in a dairy farm

Table 1: Results from the water analysis performed in the dairy cow farm to several inputs and outputs points.

Parameter	Trough	After cleaning the milking machine	After cleaning milking parlor	Yard flushing
Conductivity, mS/cm	0.7	-	2.5	17.1
pH	7.9	-	6.9	7.5
Suspended solids, mg/L	< 10	-	7,300	30,400
Turbidity, NTU	1.6	-	-	-
Coliforms, cfu/100mL	$1.1 \cdot 10^5$	-	$4.6 \cdot 10^8$	$4.4 \cdot 10^7$
E. coli, cfu/100mL	$1.3 \cdot 10^3$	-	$2.0 \cdot 10^8$	$8.0 \cdot 10^4$
N Kjeldhal, mg N/L	3	-	761	3,219
COD, mg O_2/L	-	95	-	39,724
BOD, mg O_2/L	-	68	-	6,525

3.2 Pig and broilers units

Water cycles in the pig and broiler units were simpler than that of a dairy farm, since the two main water uses were for drinking water, and for cleaning purposes. Being 3.5 and 7 m^3/d the total daily consumption of water in a 20,000 broilers unit and a 1,100 pigs unit, respectively. Most of the water was used as drinking water for the animals (81.5 and 96.2 % in the broiler and pig unit, respectively), and the rest was used for cleaning the barn after removing the animals. In these examples, water samples (Table 2) from animal troughs also presented some bacterial contamination ($4.3x10^3$ and $3.8x10^4$ total coliform cfu/100mL in the broiler and pig unit, respectively), and wastewater from cleaning the barns also had high bacterial contamination ($2.2x10^8$ and $1.4x10^9$ total coliform cfu/100mL in the broiler and pig unit, respectively), and high suspended solids values (6,320 and 320 mg/L in the broiler and pig unit, respectively).

Table 2: Results from the water analysis performed in the pig and broiler unit to several inputs and outputs points.

Parameter	Pig trough	After cleaning the facility (pig)	Broiler trough	After cleaning the facility (broiler)
Conductivity, mS/cm	0.7	1.4	0.6	2.0
pH	7.1	6.6	7.7	6.5
Suspended solids, mg/L	-	320	-	6,320
Turbidity, NTU	29.8	-	2.7	>800
Coliforms, cfu/100mL	$3.8 \cdot 10^4$	$1.4 \cdot 10^9$	$4.3 \cdot 10^3$	$2.2 \cdot 10^8$
E. coli, cfu/100mL	$2.0 \cdot 10^4$	$9.3 \cdot 10^7$	7	$2.8 \cdot 10^7$
N Kjeldhal, mg N/L	4	56	1	341
COD, mg O_2/L	-	18,538	-	-
BOD, mg O_2/L	-	17,100	-	-

Researchers from the University of Arkansas made a report of the life cycle analysis of water use in US pork production, and when reporting data of the water cycle in a swine facility, they considered 80% of the water use for drinking purposes, 7% for washing the facility, 12% for cooling the animals, and 1% for domestic use (Matlock et al., 2014).

Considering the information mentioned above, it could be envisaged the possibility to use reclaimed water from wastewater treatment plants for livestock drinking purposes when incorporating a tertiary treatment based on membranes and a disinfection step. Furthermore, reclaimed water could be also used for cleaning surfaces (barns, milking parlor...), in these cases a tertiary treatment based on membranes could be used for cleaning purposes, and a disinfection step could be also incorporated if considered. It is important to highlight the possibility to recycle water within the farm by treating wastewater with an anaerobic membrane bioreactor. This technology combines anaerobic biological treatment with membrane filtration with the potential to generate a high quality effluent, which could be treated with a disinfection step to increase the quality of the outgoing water.

4 Conclusions

In conclusion, in livestock activities the main use of water is for animal drinking purposes. Therefore, establishing strategies to potentially use reclaimed water from treatment plants or recycling the own wastewater generated in the farms for animal drinking are the key points to reduce the use of water in farming activities. Membrane filtration followed by a disinfection step could be a good methodology to improve the quality of wastewater and used it for livestock drinking purposes or cleaning usages.

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Reduction of clogging in agricultural irrigation networks

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Abstract

Biofilms formed in irrigation system can have important implications in horticultural production, because they can cause a variety of problems including clogging and corrosion. They are also commonly associated with garden hoses, rain barrels, and water features including ponds and fountains.

Emitter clogging is one of the bottlenecks to restrain the application and popularization of drip irrigation technology use with reclaimed water. In some locations, the high concentration of carbonates and calcium in water cause the precipitation of calcium bicarbonate that causes big problems in irrigation system. This chemical scaling could favour the formation of biofilm in the flow path of the emitter and it can increase the clogging.

The objective of present assay is test the standard maintenance cleaning of irrigation system with nitric acid against a novel system based on the injection of CO2 in the water.

1 Introduction

Ubiquitous, but often unseen, biofilms can have important implications in horticultural situations. Biofilms are likely present in every water system and pipe, filter, pump, tank, hose, emitter and nozzle in a nursery, greenhouse, field crop, garden, etc. Not surprisingly, biofilms are also commonly associated with irrigation systems where they can cause a variety of problems including clogging and corrosion. They are also commonly associated with garden hoses, rain barrels, and water features including ponds and fountains.

A biofilm is a community of microorganisms that colonize moist surfaces. They are common in all the habitats and can be beneficial or harmful depending on the microorganisms present and the situation. This is also true for horticultural systems, where their environmental conditions are often ideal for biofilm development (moist and warm) and where the presence of pathogenic microorganisms can have significant economical consequences.

Emitter clogging is one of the bottlenecks to restrain the application and popularization of reclaimed water, with drip irrigation technology. It is tightly related to the formation of biofilms attached on drip irrigation pipes and emitters (Gamri et al 2014; Puig-Bargués et al. 2005; Zhou, B. et al. 2013). The formation of biofilm in the emitter depends on design, water flow velocity, water pressure (Gamri et al 2014).

At the same level, the risk of diseases associated to these microorganisms, and high and unbalanced level of nutrients are very important legal and logical restrictions for the general use of reclaimed water for fresh vegetables.

The objective of present assay is testing the standard maintenance cleaning of irrigation system with nitric acid against a novel system based on the injection of CO_2 in the water.

2 Material and Methods

The assay has been developed at IRTA Torre Marimon (Caldes de Montbui, Barcelona, Spain) facilities. Two water qualities were applied for irrigation: reclaimed and well water. Reclaimed water comes from the Waste Water Treatment Plant of Caldes de Montbui village 2km far from our facilities, which treats urban and industrial wastewater. The wastewater plant has a secondary treatment with disinfection. This water is stored in a reservoir of 27 m^3 without disinfection. To avoid oxygen concentration depletion and consequently anoxic conditions, one submerged pump move the water from the bottom to the top of the reservoir 6 times during 5 minutes along the day. Well water is obtained from IRTA phreatic facilities. A disc filter has been placed before the irrigation pipe in each treatment, in order to reduce and/or avoid the obstruction derived from water suspension particles.

Two maintenance treatments were tested, nitric acid diluted in the water and CO_2 injection. Nitric acid diluted on the water through a venturi system (Dosatron

International SAS, France), and CO_2 injection from a liquid tank (Air Products MATGAS) into the irrigation water system.

Reclaimed water without any chemical added was used as a control treatment, and well water was used to compare biofouling appearance in normal water used for irrigation at IRTA facilities.

Two types of irrigation drippers were tested: Compensated dripper (model PCJ Junior) and Integral dripper (model Uniram RC) from Netafim, Israel. Nominal flow was 2 $L.h^{-1}$ at the working pressure (2 $Kg.m^{-2}$). For each treatment six polyethylene pipes of 16 mm and fifteen meters length were used and three pipes with the two dripper types. The distance between emitters was 0.5 m.

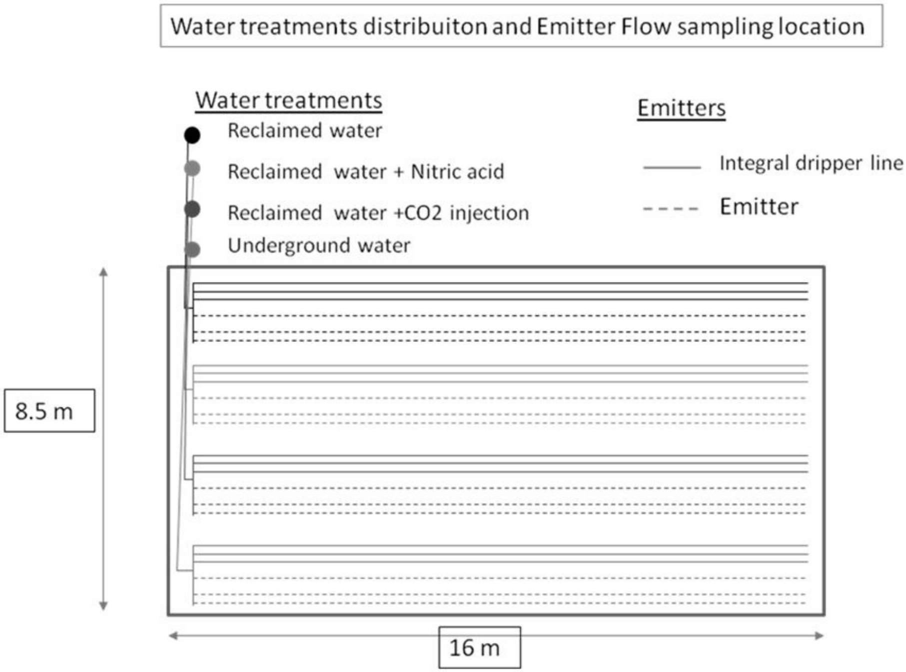

Figure 1. Scheme of water treatments distribution

Daily irrigation is scheduled at 9:00 and 16:00 hours during 10 minutes. The water is stagnant from 9:10 to 16:00 h and from 16:10 to 9:00 h of the following day. As an example, the daily water flow in spring, in the essay conditions was: 0.040 $L.min^{-1}$ * 20 $min.day^{-1}$ = 0.8 $Litres.day^{-1}.emitter^{-1}$.

For the detection of biofilm build-up monthly water flow is measured in 3 drippers/pipe x 6 pipes/treatment collecting water delivered during 2 minutes from each dripper and we determine the amount of water volumetrically. Similarly, it has been measured the working pressure at inlet pipe at the end of the pipe with a water pressure meter. The effect of emitter clogging on flow pressure was analysed.

Weekely, the water‘s pH from different treatments was measured (pHmeter, Orion).

Figure 2. Scheme of the emitter sampling point

Microbial analysis / characterization of the biofilm

The presence of biofilms, microorganisms, in different water samples and attached to pipe walls and emitters of irrigation network were evaluated. Different inlet waters and pipe sections for each different water treatment were sampled (Figure 1) and placed in sterile sampling flasks and transported to the laboratory in insulated cold boxes to examine and characterize biofilm growth. The methods used for determining the density of aerobic and facultative anaerobic heterotrophic bacteria were spread plate technique and membrane filtration method (Hallam, *et.al*, 2001 and Rasmus, *et.al*, 2002).

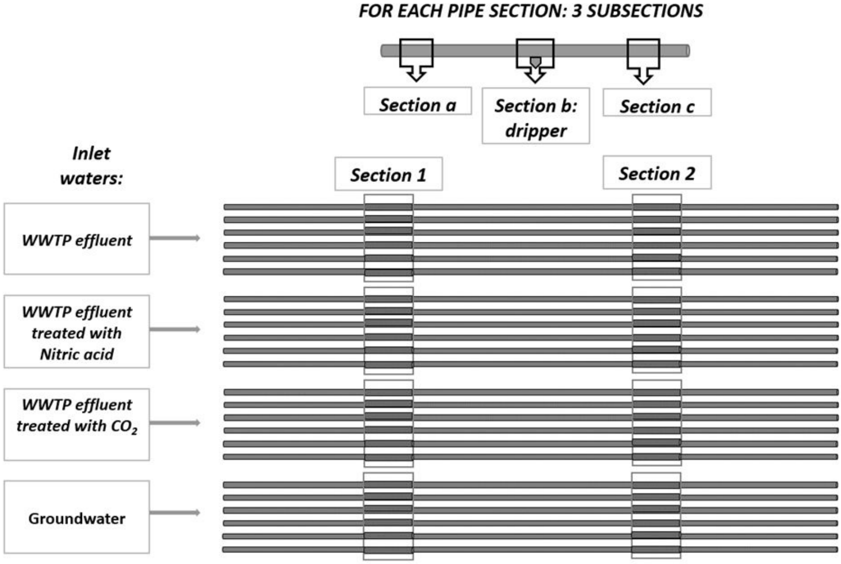

Figure 3. Scheme of irrigation pipe and sampling point locations in each pipe.

In order to decide the most suitable media for incubation, Standard Methods Agar (SMA) and R2A agar were tested and compared with spread plate technique, to choose the most suitable non-selective media for nutrient supplying. Analyzing the results, R2A media was selected as it showed higher bacterial growth than SMA media. After selecting the R2A as the superior medium for these measures, the protocol was set, each sample was tested in duplicate and colonies were counted after filtration in a 0,45µm membrane filter and incubation at 22ºC for 7 days (Hallam, *et.al*, 2001). Results were reported as colony forming units (FCU) per mL or per unit area of pipe surface.

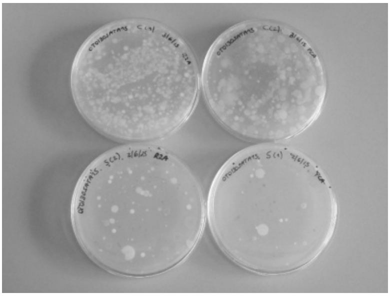

Figure 4. Agar media comparison test

During the sampling, each pipe section was cut with a circular saw and biofilm was collected by swabbing the entire surface of the pipe (Hallam, *et.al*, 2001). Swabs were immediately transferred into a volume of 10 ml of ¼ strength Ringer solution. Bacteria extraction was done vortexing vigorously the swab to release the bacteria into the sterile Ringer solution. The number of heterotrophic bacteria of the solution was counted using spread plate technique. Final bacterial concentration was reported as colony forming units (ufc) per unit area of pipe surface, which was determined for each pipe piece.

Figure 5. Pipe section sample before bacteria extraction

Besides, the four different inlet waters were analyzed by membrane filtration method to be able to detect lower number of microorganisms by testing larger volumes of sample. Each sample of water was filtered applying vacuum. The 0,45 µm membrane filter with the retained particles was placed onto the R2A agar media surface, ensuring there were no air bubbles between the filter and the media. The R2A agar was then incubated at 22ºC for 7 days. The final results were reported as colony forming units (FCU) per mL or per unit area of pipe surface.

3 Results

After one year of treatment, it was observed that CO_2 and nitric injection decreased water pH at the same level (Fig. 6) this result has importance for end users due to the management difficulty of nitric acid and the increase of nitrogen concentration in the water. The difference of pressure between inlet water end pipe increase only in reclaimed treatments (Fig 7) and emitters flow have small changes in one sample (Fig 8). The study will continue during autumn season to determine possible season effect between maintenance methods and the effect of accumulated time of functioning hours of irrigation and hour of water stagnation in the pipes.

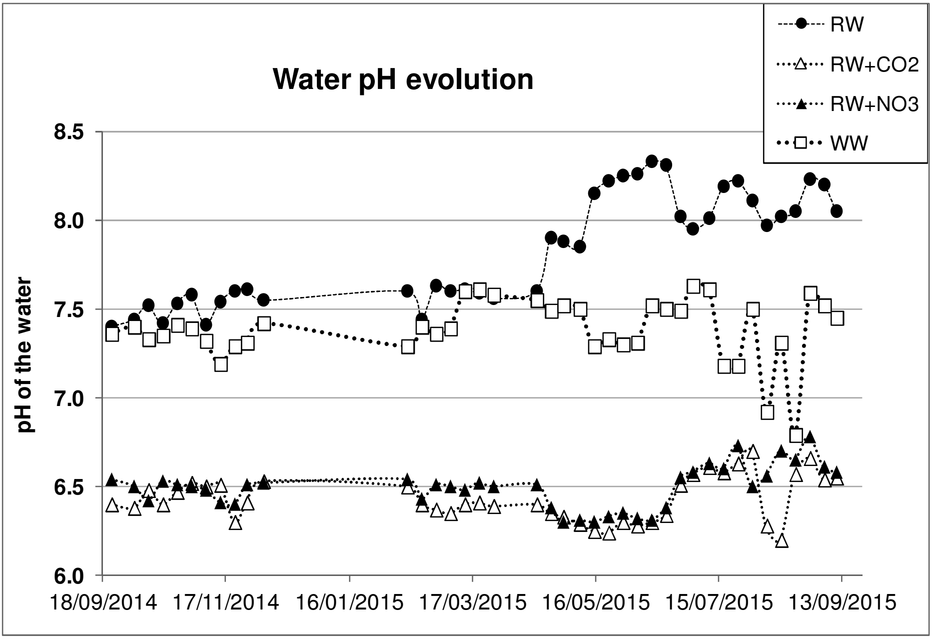

Figure 6. pH of the water of each treatment. Simbols are one value per day of measure. R=Reclaimed, RW+CO2 = reclaimed+CO2, RW+NO3= reclaimed+nitric acid, WW=well water.

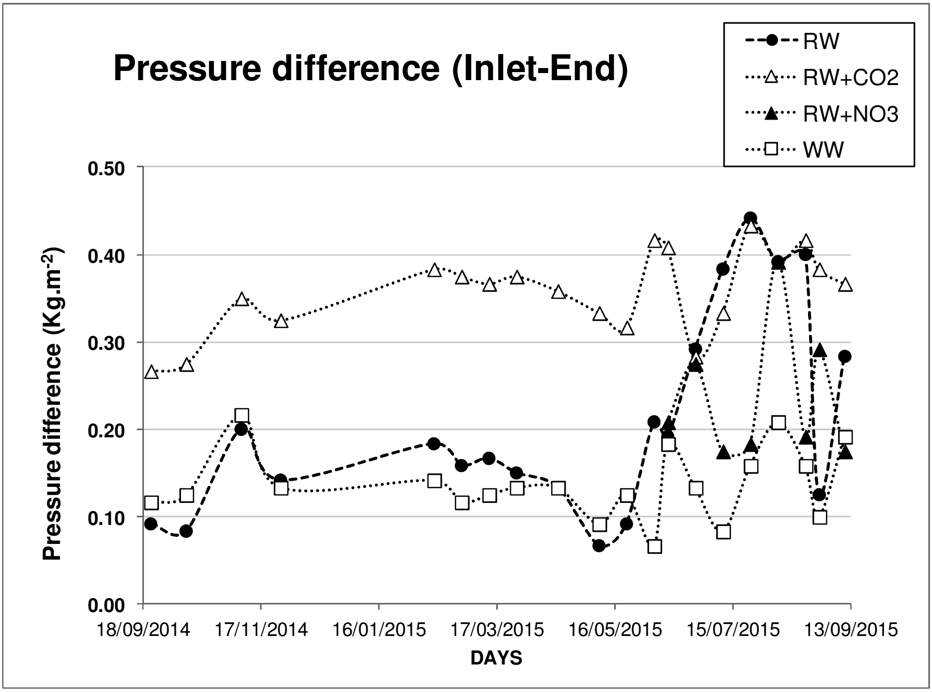

Figure 7. Water pressure difference between inlet and end of the pipe. Values are the average of 6 pipes per treatment. R=Reclaimed, RW+CO2 = reclaimed+CO2, RW+NO3= reclaimed+nitric acid, WW=well water.

The water flow in drippers was not affected by clogging in reclaimed water and integral dripper (Figure 7 right). In external dripper, in June, sampling water flow decrease in reclaimed and well water (Figure 7 left).

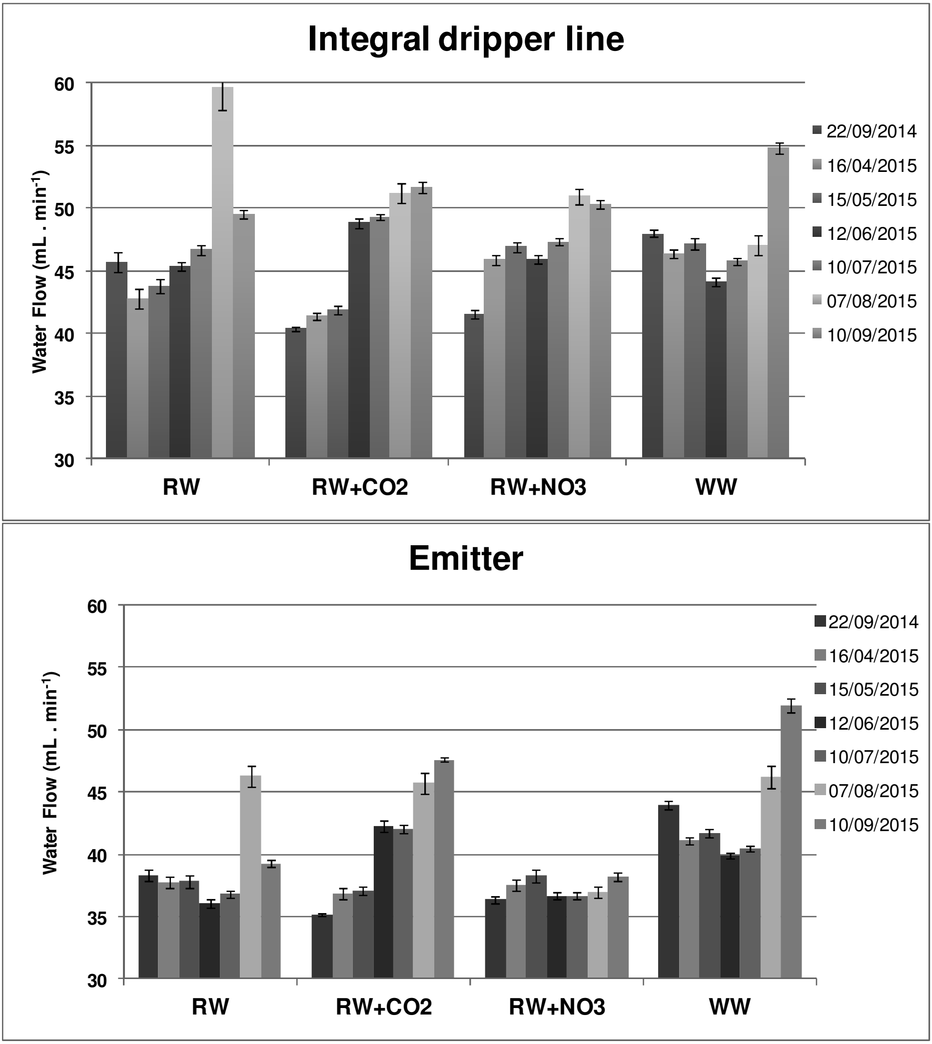

Figure 8. Water flow in integral dripper (up panel) and emitter (bottom panel) in seven sampling days. Values are the average of 9 drippers per treatment ± standard error. R=Reclaimed, RW+CO2 = reclaimed+CO2, RW+NO3= reclaimed+nitric acid, WW=well water.

Biofilm formation results:

Results (two samples) show that there was a light increase of bacterial count in the integral emitter in June (Figure 9). Bacterial count in reclaimed water was 4100 $fcu.mL^{-1}$ in May and 76364 $fcu.mL^{-1}$ in June and in well water was 2320 $fcu.mL^{-1}$ in May and 87143 $fcu.mL^{-1}$ in June. Bacterial count in pipes showed values ranged between 1 and 502 $fcu.mm^{-2}$ in may and 1 and 1212 fcu mm^{-2} in June.

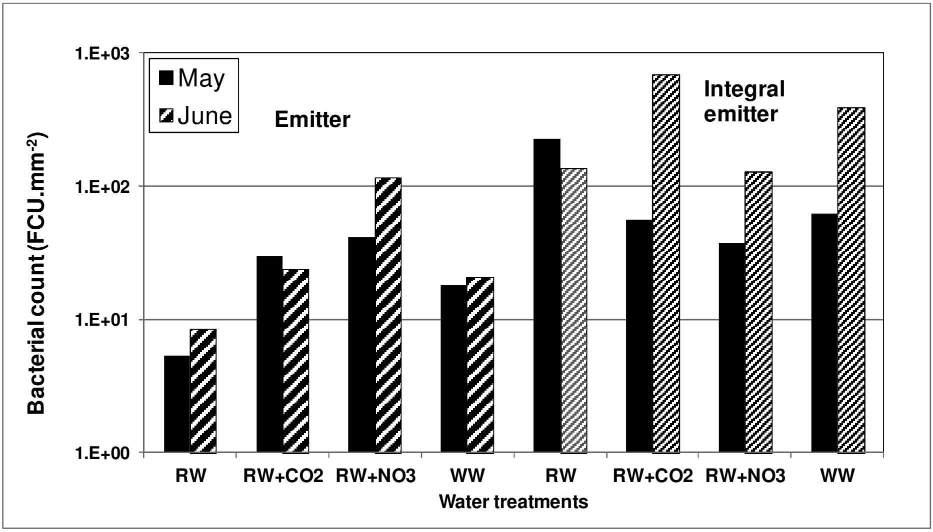

Figure 9. Two sample (May and June 2015) results of bacterial count in each emitter type*water treatment combination. R=Reclaimed, RW+CO2 = reclaimed+CO2, RW+NO3= reclaimed+nitric acid, WW=well water.

4 Discussion and preliminary conclusions

At these moments of the assay, there are no clear effect of water treatments and water origin in emitter clogging. There is a low relationship between emitter or dripper water flow and UFC mainly in emitters.

In addition, integral emitters show great UFC and water flow than emitters, which is showing that water flow resistance is highly associated to boundary layer between emitter and flow path into the dripper than biofilm.

According these results, CO_2 treatment is a very interesting agronomical option to control water's pH, UFC, increasing water flow, besides this treatment has less negative effects on environment compared to nitrogen pollution and also workers safety during acid management is avoided.

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Anaerobic membrane bioreactor technology for integrated water reuse and waste management in rural zones

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Abstract

Anaerobic membrane bioreactors (AnMBR) are emerging as a sustainable way for treating and recycling the organic fraction of rural wastes. This paper provides a screening of several rural wastes and the optimal membrane configuration to optimize productivity in terms of biogas production. Biodegradability and biogas production of 6 different rural wastes were tested in anaerobic batch tests: cheese whey, slaughterhouse wastewater, dairy manure, pig manure, winery wastes and fruit and vegetables wastes. All the tested wastes could be successfully degraded under anaerobic conditions but cheese whey presented the most promising results: fast biodegradation and high biogas quality production.

After the waste screening, a bench scale AnMBR was set up with a feeding mixture of 50% whey - 50% wastewater. At steady state conditions the AnMBR could properly degrade up to 85% of the inlet COD, biogas production was about 800 mL/h and its quality was nearly 65%. In order to investigate the optimal membrane configuration, flat sheet and tubular membranes were tested and critical flux experiments were performed.

Results from this study were used for the design and construction of a pilot scale reactor (50 l/day), which will be operated for one year to demonstrate the feasibility of the technology to reclaim water, to obtain biogas and to improve the current waste management strategies in rural zones.

Abbreviations

AnMBR	Anaerobic Membrane Bioreactor
COD	Chemical Oxygen Demand
BOD	Biological Oxygen Demand
TSS	Total Solids Suspended
VSS	Volatile Solids Suspended
TIC	Total Inorganic Carbon
TOC	Total Organic Carbon
OLR	Organic Loading Rate
HRT	Hydraulic Retention Time
SRT	Solids Retention Time
VFA	Volatile Fatty Acids

1 Introduction

Anaerobic membrane bioreactor (AnMBR) has recently emerged as a potential technology for high-rate anaerobic treatment by combining anaerobic biological treatment with membrane filtration.

Under well-controlled conditions, anaerobic digestion is an attractive technology to integrate wastewater reclamation with organic waste management, having the potential to provide useful products such as reclaimed water with a high quality effluent, biogas and organic fertilizer, representing an opportunity to decrease environmental pollution. The anaerobic digestion also offers significant advantages when compared to aerobic treatment, in terms of less production of sludge, ability to deal with high organic loads, low cost and biogas production (Shaddoud et al., 2007).

However, different factors such as substrate composition and quality, environmental factors such as temperature, pH and organic loading rate, and microbial dynamics contribute to the efficiency of the anaerobic digestion process, and must be optimized to achieve maximum benefit from this technology, in terms of both energy production and organic waste management (Cavinato et al., 2010).

Also, bioreactor design has found to exert a strong influence on the performance of a digester. Batch reactors, a one stage continuously fed system and a two stage or multi-stage continuously systems are the three major groups currently in use. However, their drawbacks still limit their implementation in full-scale plants (high costs of membranes, membrane permeability, accumulation of volatile fatty acids, etc.).

Following these evidences, this paper considers the anaerobic digestion at both batch and bench scale as a preliminary step to assess the next pilot-plant design and construction of an integrated treatment able to treat wastes and wastewater and recover biogas and reclaimed water in rural areas.

2 Waste screening and selection

The feasibility of using different rural wastes was performed and it was tested at laboratory scale. Particularly, after a bibliographic analysis of potential candidates, those wastes most commonly produced within the geographical area were selected: cheese whey, slaughterhouse wastewater, dairy manure, pig manure, winery wastes and a mixture of fruit and vegetables wastes. Table 1 shows the characterization of the wastes considered during preliminary lab scale experiments.

Table 1: Rural waste characterization

Waste	Cond mS/cm	pH upH	TSS mg/l	VSS mg/l	COD g/l	TIC mg/l	N Kjeldhal mg/l
Cheese whey	24	4.5	10430	9340	76.2	9	1269
Slaughterhouse wastewater	5.7	6.6	1699	1670	5.4	47	289
Dairy manure	6	7.6			25.7		1.9
Pig manure	43	7.4	26700	19100	53.2	121	8316
Caldes Montbuí wastewater	1.7	7.8	106	85	0.3	75	27

1L batch tests using an AER-208 respirometer (Challenge Technology) were used to assess the potential rate of digestion for each waste. Thus, each single batch, containing 5 g/L of VSS from anaerobic sludge and the required amount of waste corresponding to 5 g/L of COD were tested. Figure 1 shows the set up for the batch experiments performed while monitoring the quantity of biogas produced.

Figure 1: Anaerobic tests performed at lab scale

From the results obtained, it was seen how the vegetables and the cheese whey presented the higher rates of biogas production. Biogas rate and its methane content reached the maximum in 18 – 20 days for all of them (data not shown).

After waste screening, the final waste selection for the bench scale and pilot-plant operation was done accordingly to the results obtained from their characterization and their biogas quality production listed in Table 2.

Table 2: Biogas quality of tested wastes

Waste	Biogas quality (% Methane)
Cheese whey	94
Slaughterhouse wastewater	72
Dairy manure	81
Pig manure	88
Winery wastes	85
Fruit and vegetables wastes	40

From the tests at lab scale, it was seen how cheese whey presented the higher biogas quality with a higher percentage of methane and high rates of biodegradability (up to 99%). However, the alkalinity was low (5 g/L CaCO3) and raw whey would tend to acidify, being difficult to treat by anaerobic digestion. Hence, mixing whey with municipal wastewater to reduce the organic concentration would solve this problem of instability (Ergüder et al., 2001 and Malaspina, 1005).

According to the fact pointed before, it was decided to use a mixture of cheese whey and municipal wastewater with of 50% whey - 50% wastewater as a starting point in order to prevent acidification and ensure stability for the whole bench scale operation. During the last stage of pilot plant operation, the mixture ratio will be then optimized.

3 AnMBR bench scale evaluation

After batch laboratory tests, a one stage bench scale anaerobic reactor fed with the decided mixture of cheese whey and municipal wastewater was operated with the main goal to understand and optimize the system to later on warranty an optimal pilot plant operation.

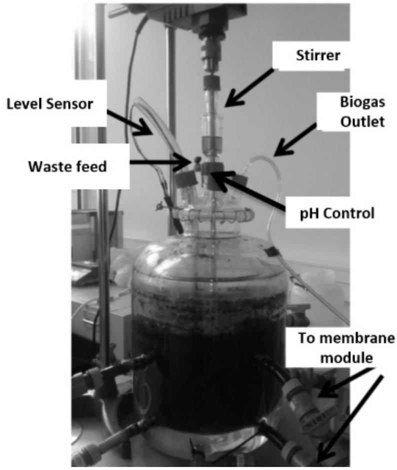
The reactor consisted in a perfectly sealed jacketed glass reactor with a capacity of 10L. Figure 2 shows the experimental set-up used. Its operation started on 7th of October 2014 and it was operated at an average HRT of 9 days, ranging from 6.7 to 11 days.

As temperature of the mixed-liquor affects the COD removal efficiencies, a mesophilic range of 35 ºC was kept in the reactor to enhance better COD removal efficiency. The pH was automatically kept at a value of 7.0 dosing NaOH 0.1 M.

Membrane separation was an effective method to achieve complete separation of solids from the effluent. Thus, the reactor was coupled to an external polymeric microfiltration membrane module used to separate solids from permeate. The external module consisted on a 40 cm^2 polyethylene flat sheet membrane with a pore size of 0.2 µm.

A constant inner level was maintained during all the experimentation using a programmed level device. When permeate flow solution was obtained and the reactor level decreased, the waste feed was dosed in an automated form.

Figure 2:
Anaerobic MBR bench scale reactor



The seed sludge for the reactor was obtained from a full-scale anaerobic wastewater treatment plant in Manresa. The feeding mixture for the AnMBR bench scale consisted of 50% whey - 50% wastewater, resulting in an average OLR of 6 g COD/(m^3·day). TSS, VSS, inlet and permeate COD, inlet and permeate BOD5, alkalinity of the permeate, pH of the waste feed, VFA, redox potential and total biogas production were measured periodically.

The whey used was taken from a local cheese manufacturer and it was kept frozen to prevent degradation. Every day, the mixture of melted whey and wastewater was prepared and kept at 4ºC.

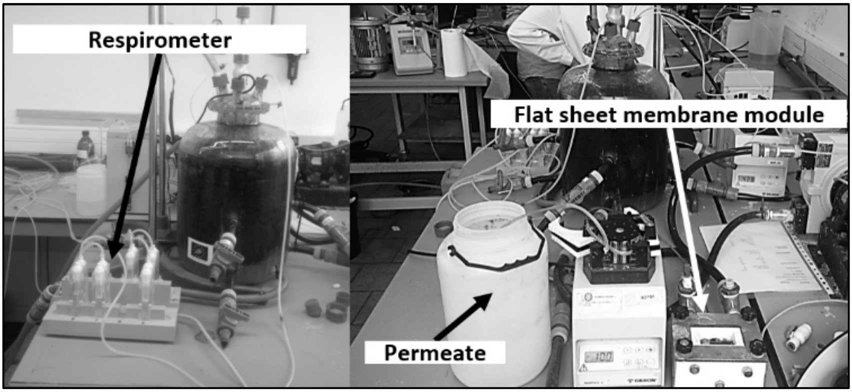


Figure 3: Anaerobic MBR configuration

The chemical composition of the substrate mixture is summarized in Table 3 and the notable characteristic of this effluent is the high COD values due to the high percentage of lactose content in the whey.

Table 3: Chemical characteristics of whey and wastewater mixture (06/10/2014)

Parameter	Units	Concentration
pH	upH	6.5
TSS	mg/L	5320
VSS	mg/L	5280
COD	g/L	39
TIC	mg/L	331
TOC	g/L	11
N Kjeldahl	mg/L	245
P total	mg/L	120
Sulphate	mg/L	128
Alkalinity	mg CaCO3/L	1260

Biogas production was continuously monitored with the AER-208 Respirometer. Biogas quality (CH_4 content) was determined by absorbing CO_2 in potassium hydroxide (KOH) alkaline solution, with the liquid replacement system (LRS) technique.

Reactor VFA content were periodically monitored and analysed with a commercial organic acid test from Nanocolor. The determination was carried out in two main steps, firstly an esterification of organic acids with ethylene glycol, and secondly, a conversion of the esters to hydroxamic acids which subsequently react with iron (III) ions to form red coloured complexes.

One of the most important targets to achieve during an AnMBR operation was to reduce the COD in the effluent before its reuse. Thus, the organic carbon concentrations both in the influent and effluent were monitored to estimate the overall removal efficiency. As seen in figure 4a, the influent ranged from 23 to 37 g/L and removal efficiencies varied from 70 to 95%. Currently, after 270 days of digester monitoring, the reactor properly degraded up to 85%.

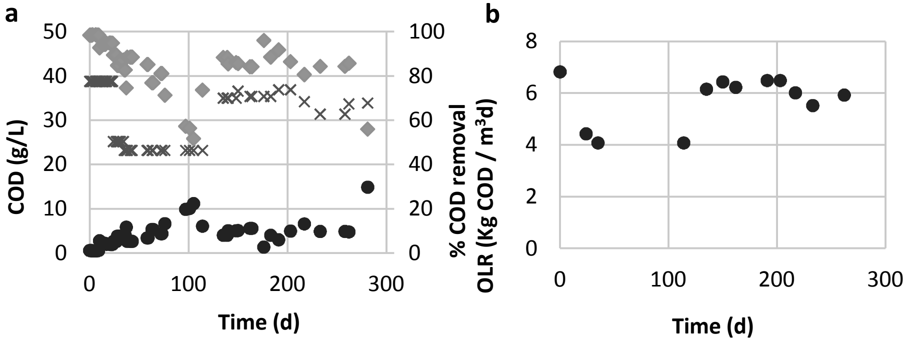


Figure 4: (a) Organic loading rate. (b) COD in the raw feeding mixture (×), COD in the permeate (●) and percentage removal of COD (◆).

From figure 4b it can be seen how the organic loading rate (OLR) in the reactor ranged from 4 to 7 gCOD/(L.day). In terms of mass organic loading rate, it ranged from 0.05 to 0.78 kgCOD/(kgVSSv.day), influenced by SRT and activity of the sludge. The operating conditions were an average HRT of 9 days and no sludge purging took place.

In anaerobic digestion process, changes in OLR, temperature, or levels of toxics could lead to changes in methane and VFA production, the main products of microbial transformation process of organic materials. The VFA are intermediate compounds (acetate, propionate, butyrate, lactate), produced during acidogenesis. In most cases, anaerobic digestion process instability will lead to accumulation of volatile fatty acids (VFA) inside the digester, which can lead to a drop of pH value. In the crude waste mixture VFA were quantified to be 1.4 g/L and the average VFA levels of the permeate ranged from 0.2 to 4.5 g/L, with no effect on the reactor performance. Figure 5a shows the whole experimental period during the digester functioning.

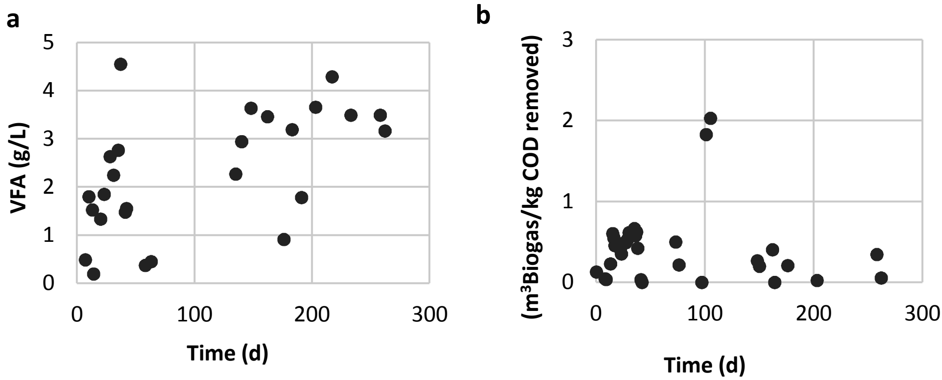


Figure 5: (a) Total VFA inside the reactor. (b) Biogas production.

AnMBRs can also play a key role in energy recovery due to their capacity to produce CH_4. After 270 days of digester monitoring and operating at around 35ºC in the mesophilic range, the reactor could properly degrade up to 85% of the inlet COD, biogas production reached 0.8 L/h and its quality reached 75%. However, during the operation, some leakage episodes occurred with no special significance for the overall process.

After 300 days of reactor running, the temperature conditions of the feed mixture was changed keeping it at room temperature to previous characterize the behaviour of the cheese whey stored at higher temperatures for longer times. This is a preliminary step before starting with the pilot plant operation, where the feed mixture will be stored at room temperature. Also, half of the sludge volume was purged.

After changing boundary conditions, first results confirm an increase on biogas production and a reduction of VFA inside the reactor, ensuring the well running of the reactor. Expected values from the stored feed mixture are higher VFA concentration and slightly lower pH and COD, attributed to the biological degradation of the whey with the loss of various volatile organic compounds during storage.

4 Membrane configuration selection

Even though AnMBR are usually operated at lower membrane permeate fluxes than aerobic ones, membrane fouling is still one of the main disadvantages of MBRs because it hinders the operation of the system in a constant way. AnMBR are characterized by lower sludge filterability, which favour membrane fouling.

The bench scale AnMBR reactor had an external membrane configuration and several membranes were tested: tubular polymeric, tubular ceramic and flat sheet. Table 4 presents the available information for the different membranes tested at bench scale.

Table 4: Membranes tested at bench sale experiments

Manufacturer	Configuration	Membrane type	Membrane pore size
Kubota	Flat sheet	Polymeric MF	0.4 µm
Atech-innovations	Tubular	Ceramic MF	0.2 µm
Pentair	Tubular	Polymeric UF	300 kDa

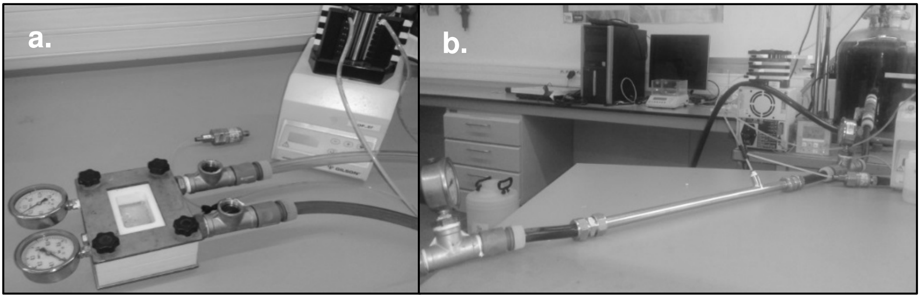


Figure 6: (a) Flat sheet MF membrane and (b) tubular ceramic MF membrane setup.

External membrane configurations of AnMBR are mostly influenced by transmembrane pressure (TMP) values and cross-flow velocities. At bench scale, in order to evaluate fouling at different operational conditions, short-term fouling experiments for each membrane configuration were performed at different cross-flows and permeate flux while monitoring pressure increase. Experiments using cross-flow velocities of 2 and 3 m/s and permeate fluxes of 10, 15 and 20 LMH were performed.

Also, critical flux measurements were performed to identify the flux at which the transmembrane pressure started to deviate from the pure water line and irreversible fouling appeared on the membrane surface.

One of the most common procedures for the determination of the critical flux is the flux-step method (Le Clech et al., 2007). In this case, the methodology applied to determine the critical flux of the different membrane modules was an improved version of the flux-step method proposed by van der Marel et al (2009).

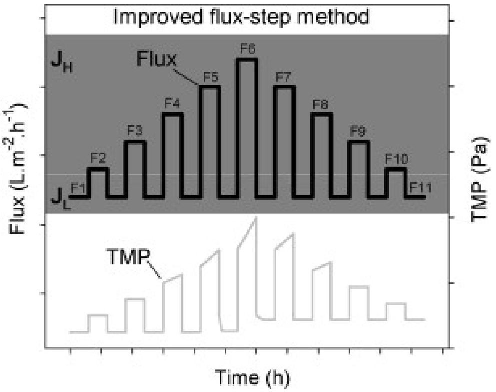


Figure 7: Improved flux-step method proposed by van der Marel et al (2009)

Critical flux experiments were performed for the bench scale AnMBR reactor fed with a mixture of 50% whey - 50% wastewater for each different membrane module.

As an example, Figure 8 shows how applying successive fluxes up to a maximum flux and back, fouling occurred at 23 LMH for the ceramic tubular module, revealing that critical flux was situated between F4 and F5. As a form of relaxation, after each flux step, an intermediate flux of 9 LMH was performed in both the ascending and the descending phase. For real relaxation, filtration should be ceased.

As shown from Figure 8, no increase in TMP during the relaxation intermediate flux occurred up till flux step F5, implying that the fouling at flux-steps F3 and F4 was reversible.

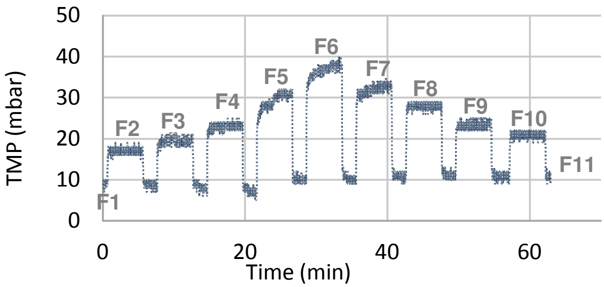


Figure 8: Critical Flux for the ceramic tubular module.

After evaluating all the experiments performed with the different membrane modules, flat sheet membranes were selected as the most suitable option due to fouling rates, investment and operational costs. Thus, flat sheet membranes were finally applied for the AnMBR pilot-plant designed.

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Water reuse in El Port de la Selva: Groundwater modelling of Soil Aquifer Treatment (SAT) for reclaimed water

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Amphos21

Abstract

We present a methodology to optimise the design of Soil Aquifer Treatment (SAT) of reclaimed water using numerical simulations of groundwater flow through the aquifer. Key variables in the design of SAT systems are the travel time from infiltration ponds to water supply wells and dilution factors of reclaimed water in pumping wells used for water supply. Using a flow and transport model, we simulate the migration of the plume of reclaimed water through the aquifer to analyse the sensitivity of travel times and dilution factors to parameters such as rainfall, infiltration rates, pumping schemes in water supply wells, aquifer porosity and hydraulic conductivity.

1 Introduction

Water shortages and scarcity of water in the entire Mediterranean basin have prompted towards an increasing application of water reclamation and reuse programs in the area. In 2014 more than 25 Hm^3 of reclaimed water have been produced in Catalunya (ACA, 2015). The use of reclaimed varies from project to project and includes irrigation, street cleaning, wetland restoration, industrial demands and environmental uses which include aquifer recharge by means of different technologies. More specifically, 16.5 Hm^3 (60% of total reclaimed water) have been used for environmental uses, 4.5 Hm^3 (18%) for recreational demands, almost 2 Hm^3 (7%) in agriculture, 2.4 Hm^3 (9%) for industrial uses and 0.3 Hm^3 (1%) for municipal applications.

In El Port de la Selva, a coastal town in Costa Brava (Northern Catalunya), population in summer increases up to 10 times. Water supply relies mainly in groundwater as surface water is very scarce and seasonal and the village location does not allow the connection with other water networks. Water scarcity and increasing demands every summer require innovative solutions to ensure water availability in the future.

Reclaimed water from local wastewater treatment facilities may constitute an alternative water source for local population (Sala and Serra, 2004).

The utilization of reclaimed municipal wastewater is one of the most promising and evaluated options in integrated water resources management. Among the various beneficial uses of reclaimed wastewater, Managed Aquifer Recharge (MAR) receives growing attention because it features environmental and management advantages. Managed recharge has provided, for a long time, means to mitigate depletion of groundwater levels, to protect coastal aquifers from saltwater intrusion, and to store water for future use (Kanarek & Michail 1996; Mills et al. 1998; Bouwer, 2000).

The recharged water can be used, among other, by indirect potable use, and this is certainly one of the most challenging water reclamation and reuse applications with a high demand in terms of safety because of the potential use as drinking and the general level of protection required for groundwater resources (Wintgens *et al*., 2008). European Union legislations (Water Framework Directive (WFD, 2000/60/CE), Groundwater Directive (GWD, 2006/118/EC), Urban Wastewater Treatment Directive (UWWTD, 91/271/EC)) do not consider specifically the requirements for MAR and only define a broad frame in which MAR may be developed (Vilanova *et al*., 2012). Additionally, Drinking Water Directive (98/83/EC) has to be taken into consideration when recharged water is used by indirect potable use. This is the most restrictive legislation and it is used as a reference in most Member States to ensure that human health is protected. In Spain, the Royal Decree 1620/2007 defines the conditions for water reuse authorization and specifies different types of reuse indicating the quality criteria for each different uses. The aquifer recharge use is explicitly mentioned in this legislation.

Additionally to legal requirements, groundwater recharge with reclaimed municipal wastewater presents a wide spectrum of technical and health challenges that must be carefully evaluated. A properly planned and managed water reuse project can produce high quality finished water (Asano and Cotruvo, 2004).

Surface spreading is the simplest and oldest method for managed aquifer recharge and is widely applied for its lower cost, easier management and maintenance and usually with less restrictive requirements (Dillon, 2005). In these systems, recharge water as treated municipal wastewater is stored in ponds to be infiltrated through the unsaturated soil and ground (vadose) zone. Where hydrogeological conditions are favorable, wastewater reclamation can be implemented relatively simply by the SAT (Soil Aquifer Treatment) process. The SAT process should be designed and managed to avoid encroachment into the native aquifer, to use only a portion of the aquifer and ensuring enough distance and transit time between infiltration basins and downstream wells. Different studies indicate that to give adequate SAT a minimum residence time of

60 days is required (CDPH, 2011) or at least 50-100 m and around 6 months is needed (Bouwer 1988; Asano and Cotruvo, 2004).

The use of reclaimed water for aquifer recharge requires a complex site analysis and specific investigations. Thus, designing a project for reclaimed water infiltration for aquifer recharge requires the collection, processing and analysis of complex information as land use, soil and aquifer characteristics, hydraulic parameters, environmental and legal restrictions, characteristics of the infiltrating water, residence time, location of nearby existing wells… (Pedrero et al., 2011).

In this communication, we present modelling results in El Port de la Selva Demoware site where a pilot study for Soil Aquifer Treatment (SAT) of reclaimed water is being implemented. A Finite Element numerical model is developed to estimate travel times and dilution factors of injected reclaimed water in infiltration basins. The model will be used to optimize quality and quantity of infiltrated water ensuring that negative potential impacts on health and environment are kept to a minimum.

During the framework of this project, we monitor water quality for both native groundwater and outflows from the water treatment plant to optimize treatment needs. The numerical model is used for quantitative analyses of sensitivity to precipitation/recharge and variable water demand/pumping rates at water supply wells.

The climate is in El Port de la Selva typically Mediterranean, with heavy rainy events at the beginning of autumn and/or spring. Average rainfall is around 600 mm/year but rain events can yield up to 100 mm in just a few days. Figure 1 shows daily rainfall for the period 2010-2015 and available data of pumping rates in water supply wells for 2014 and first months in 2015. As expected, the summer season corresponds to the dry months of the year and the highest water demand.

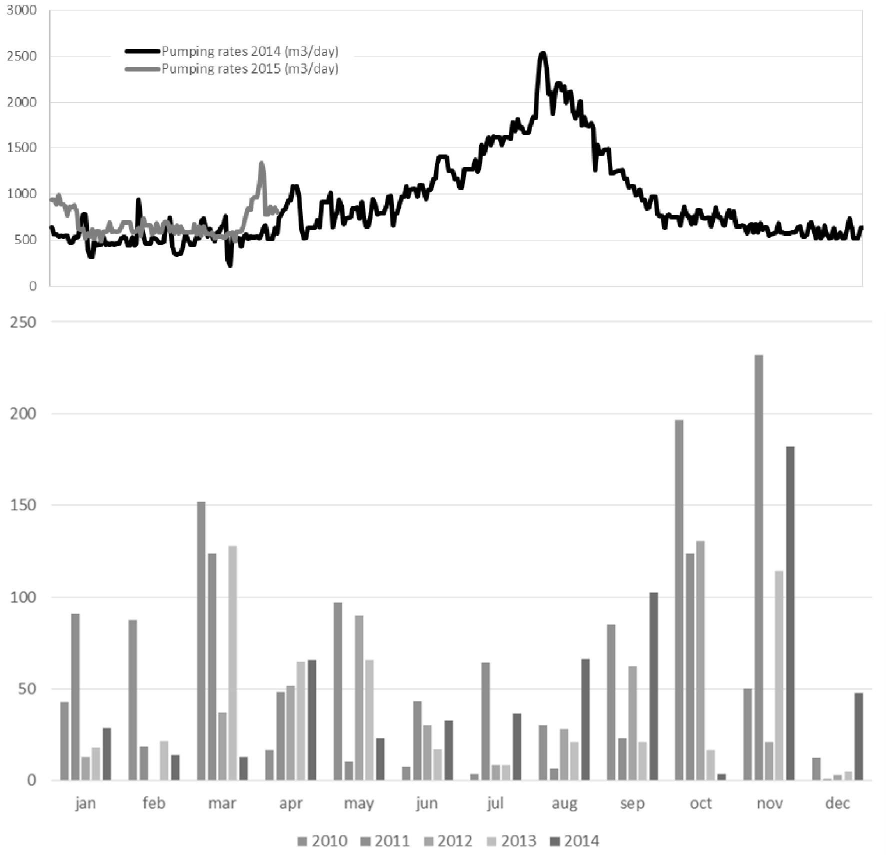

Figure 1: Daily pumping rates for 2014-2015 (top, data available until 12/4/2015) and rainfall for the period 2010-2015 (bottom, mm/month).

2 Monitoring hydraulic heads

We used a network of monitoring wells to record aquifer response to rain events and pumping operation in water supply wells (Figure 2).

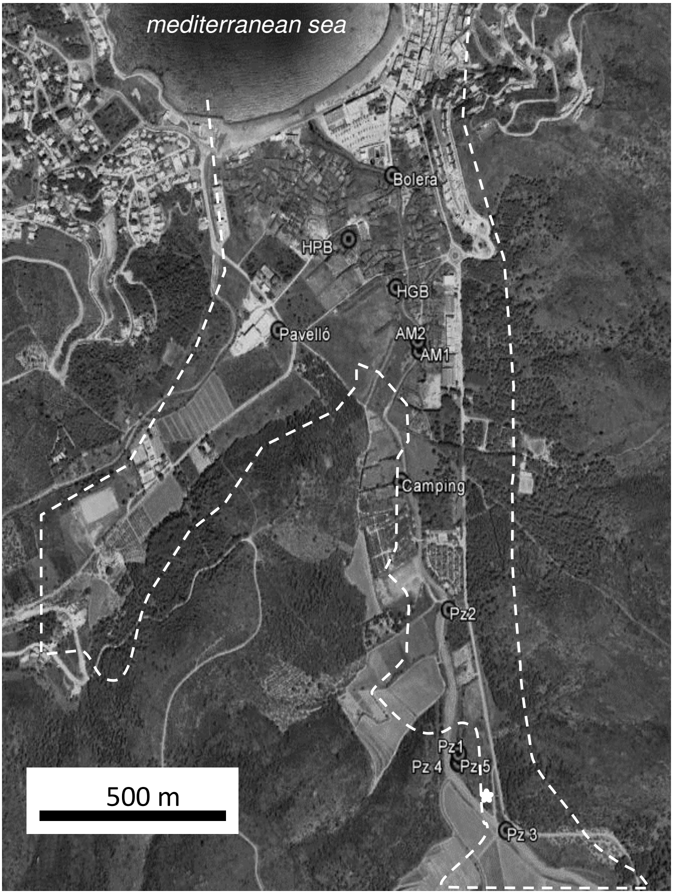

Figure 2: Location of observation wells, infiltration pond (white star) and limits of alluvial formation (white slashed line).

Infiltration ponds (white star in Figure 2) are located about 1 km upstream of water supply wells AM1 and AM2. Wells AM1 and AM2 operate for several hours a day (about 10 hours in winter and up to 20 hours in summer); head oscillations due to pumping are observed in well HGB, which is 150 m away from AM1 and 130 m from AM2. High frequency (time increments of 15 min) measurements in wells AM1, AM2 and HBG were recorded from 13/6/2014 to 27/6/2014 (Figure 3).

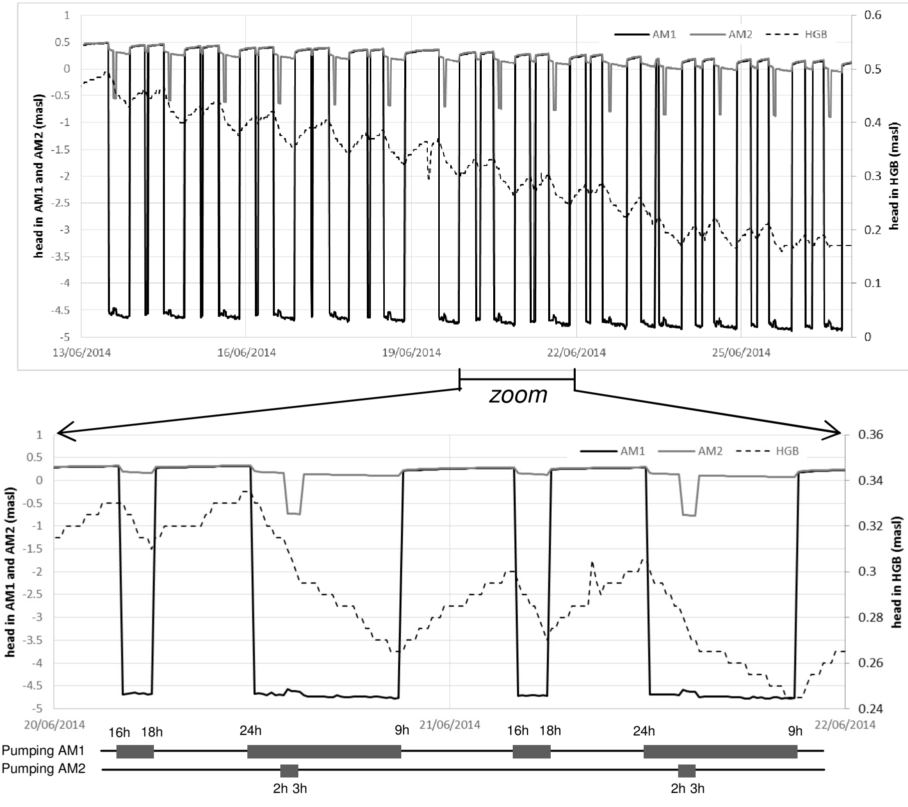

Figure 3: Evolution of hydraulic heads in AM1, AM2 and HGB and pumping scheme in wells AM1 and AM2 (note change in vertical scale for HGB).

Drawdown due to pumping is about 5 m in AM1 and 1 m in AM2 within the wells but a significant well loss (i.e. head difference within the well and aquifer next to well walls) is expected to occur. It should be noted however, that pumping in AM1 causes drawdowns of 10 to 15 cm in well AM2 and 7 to 9 cm in HGB, with this measurements being unaffected by well loss. Although steady state conditions are not yet achieved after 9 to 10 hours of pumping, these drawdowns provide valuable information on aquifer responses.

Recording of hydraulic heads started in March 2014 in some of the wells; we installed automatic divers measuring head every 8 h in June 2014 (AM1, AM2, Pavelló and HGB), March 2015 (Bolera) and April 2015 (Pz3 and Pz5). Figure 4 show all available measurements of hydraulic heads in observation wells (heads in pumping wells AM1 and AM2 not shown as will be discussed later in this section).

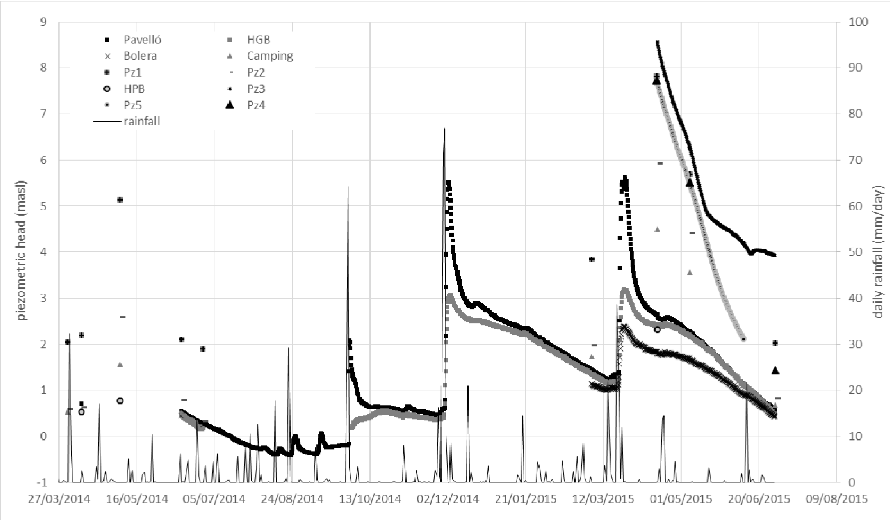

Figure 4: Evolution of hydraulic heads in observation wells and daily rainfall.

Hydraulic heads are strongly correlated with rainfall events. On September 28th and 29th 2014, 90 mm of rainfall resulted in a raise of 2 m in hydraulic head in well “Pavelló”. The first days in December 2014 a serious flooding was caused by 160 mm of rainfall in 3 days; hydraulic head raised almost 5 m in “Pavelló” and more than 2 m in HGB. From 13th to 24th March 2015 several rain events added more than 100 mm which also caused head rises of 1.5 m in “Bolera”, 2 m in HGB and 4 m in “Pavelló”. Some of the wells dry out during summer: HGB from 27/6/2014 to 30/9/2014 and Pz5 after 10/6/2015.

Hydraulic heads in water supply wells AM1 and AM2 are influenced by both pumping and rainfall events. Lowest heads occur during summer, since these are the driest months and correspond to maximum extraction rates. Recorded heads in Figure 5 for both AM1 and AM2 are substantially different depending on the time of measurement: when pumping is in operation, head is 5 m lower in AM1 and 1 m lower in AM2 compared to measurements taken when pumping is off.

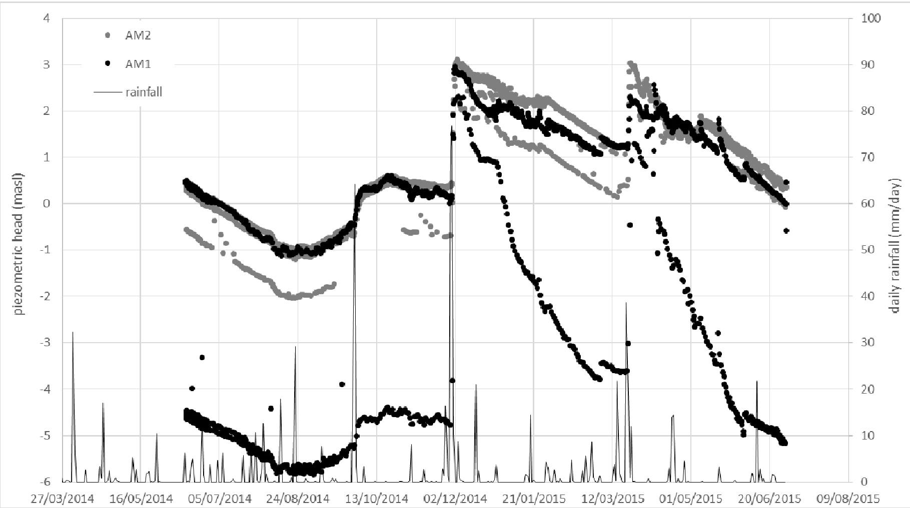

Figure 5: Hydraulic heads in pumping wells for water supply and daily rainfall.

3 Numerical modelling: calibration of flow model

We developed a 2D Finite Element numerical model to simulate grondwater flow and transport through the alluvial formation using the code FEFLOW (Diersch, 2014). The numerical model aims to reproduce hydraulic heads measured in observation wells: daily oscilations in wells located near pumping wells (shown in Figure 3) and seasonal trends as well as responses to rain events (depicted in Figure 4 and 5).

We introduced the geometry of the alluvial formation with a constant hydraulic conductivity and variable thickness, resulting in a transmisivity field variable in space but constant in time (i.e. transmissivity is not affected by changes in hydraulic head). Boundary conditions include constant head at the sea border, lateral inflow from hill slope and areal recharge. The simulation used for calibration incorporates rainfall data from two weather stations located near El Port de La Selva from the period 1/1/2013 to 12/4/2015 (877 days); both lateral inflow and recharge are time-dependant based on rainfall data. Pumping rates in water supply wells are available for the period 1/1/2014 to 12/4/2015 and it was assumed that pumping in 2013 was the same as in 2014. Details on the model development will be described in future Demoware reports. Simulated and measured hydraulic heads are shown in Figure 6 and 7.

Drawdown caused by pumping in well AM1 is much larger in the measured data (compared to the model) due to well loss, but the model reproduces reasonably well the response to rain events. As depicted in Figure 6 the model overestimates, in some cases, the rise in heads after a rain event (modelled heads in AM1 and AM2 after rainfall in December 2014) while this effect is underestimated in some other cases (e.g. march 2015 in “Pavelló”).Differences between measured heads and the numerical simulation are below 1 m for most locations, except for short time periods after rain events. The two weather stations used in the study are located 12 Km North (Portbou) and 7 Km South (Roses) of el Port de la Selva. In Mediterranean climate rainfall is highly variable in time and space (rain events may affect very small areas), for instance, on 30/9/2015 the station in Portbou measured 66 mm of rainfall while Roses remained dry. Some raises of head detected in some of the wells (e.g. 4/5/2014 in wells Pz2, Pz1 and Camping) may be caused by rain events in El Port de la Selva undetected in Portbou and/or Roses.

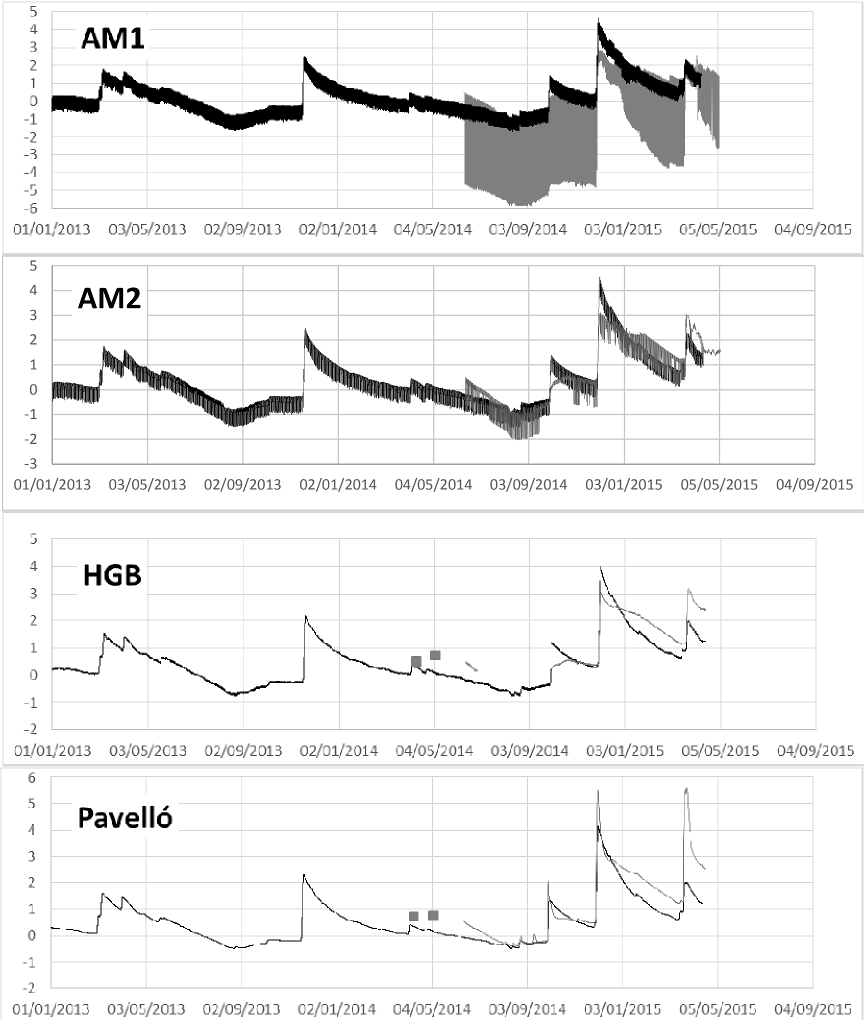

Figure 6: Measured (grey line and squares) vs. computed heads (black line).

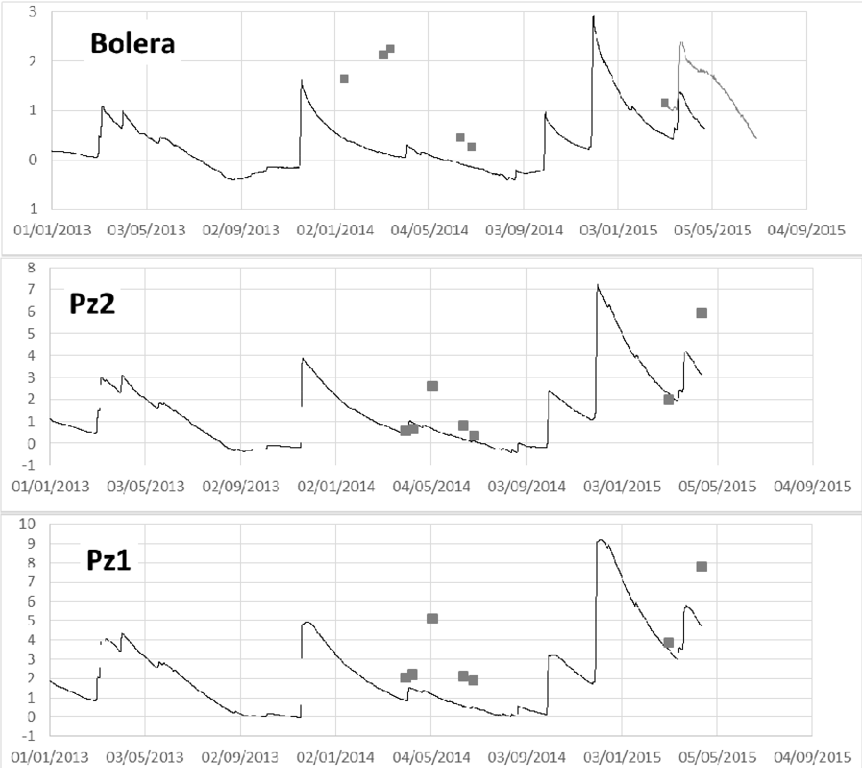

Figure 7: Measured (grey line and squares) vs. computed heads (black line).

During the next months (when more measurements are available), it will be possible to test the capabilities of the model to reproduce the behaviour of heads measured in wells Pz3 and Pz5 since at the time of writing the data set available was less than 3 months without significant rain events.

This numerical simulation for the period 1/1/2013 to 12/4/2015 (877 days) was used to calibrate the model comparing measured and computed hydraulic heads in the observation wells. The model reproduces reasonably well the response of hydraulic heads to rainfall events (Figure 6 and Figure 7) and drawdown caused by pumping in observation wells located near pumping wells (not shown here but will be discussed Demoware project reports).

4 Estimating travel time and dilution factors: forward transport simulation

After calibrating the flow model, we further incorporate transport parameters to simulate the migration of reclaimed water from infiltration basins to water supply wells. The transport model should give us the answer to two questions:

Travel time: How long does it take (for the infiltrated water) to reach the water supply pumping wells AM1 and AM2?

Dilution rate: What percentage of reclaimed water is extracted in the water supply wells?

It is important to note that we use the model to make predictions on the transport behaviour of the aquifer while we calibrated the model for flow conditions only. This is relevant because the solution to the flow equation does not depend on some parameters such as porosity, which have a major influence on the transport behaviour of the aquifer. Ideally, the model should be calibrated for transport conditions using, for example, tracer tests conducted in the field. In this transport simulation, we used a porosity equal to 30%. Within the framework of this project we will analyse if compounds already present in the reclaimed water can be used as conservative traces. For instance, caffeine (a widely studied wastewater indicator) has been found to degrade very fast under certain conditions (Hillebrand et al. 2012) and therefore may not be suitable to trace reclaimed water at large distances.

If data from tracer tests is not available, we will test the sensitivity of the model by solving the transport equation with different (realistic) values of porosity. Particle velocities and travel times are linearly dependant on porosity; for instance, reducing the porosity from 0.3 to 0.15 will imply that travel time reduces to half. Taking small values of porosity lead estimates to be on the *safe side*, i.e. to formulate answers such as “the travel time to water supply wells will be *at least* 12 months”.

The numerical simulation incorporates rainfall data from 1/1/2007 to 2/7/2015 (3100 days) for areal recharge and lateral inflow from hill slope. Data on pumping rates in wells AM1 and AM2 is only available for the year 2014 and first months in 2015; therefore we assumed pumping rates as in 2014 for all years of the simulation. We consider that infiltration basins start operating on 1/1/2007 with an infiltration rate of 200 m^3/day to obtain estimates of travel times and dilution rates under realistic conditions.

The simulated plume of reclaimed water is shown in Figure 8 after 365, 730 and 3100 days. Contour lines indicate percentage of reclaimed water within the aquifer (line 0.1 corresponds to 10% content of reclaimed water).

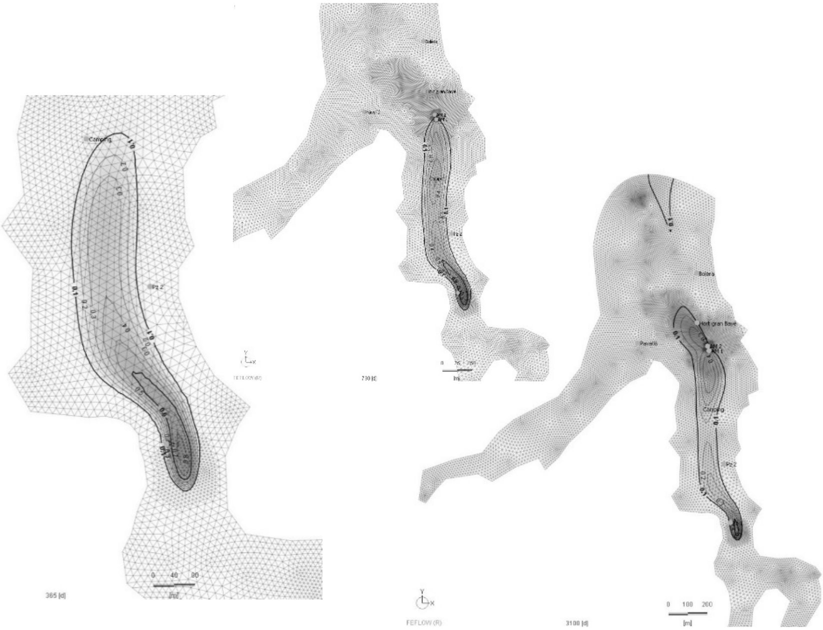

Figure 8: Plume of reclaimed water after 365, 730 and 3100 days

After 1 year, the plume reaches the observation well "camping" and it takes approximately 2 years to reach the water supply wells AM1 and AM2. The plume is not entirely captured by the water supply wells and extends towards the sea (although the total amount of reclaimed water discharging to the sea is low, as it will be discussed later).

The simulation shows that concentrations within the plume are strongly correlated with rainfall events; infiltration at the basins is constant in time (200 m^3/day) and reclaimed water accumulated near the basins during dry periods forms a *packet of water*. When an important rainfall event takes place, the packet separates from the basins and migrates downstream towards the water supply wells. One of those packets of water (originated from a rainfall event at time 366 days) is shown in the plume for 730 days near the observation well "camping" with dilution rates above 40%.

Figure shows the evolution of hydraulic heads in wells AM1, AM2 and Pz1 as well as the breakthrough curves of reclaimed water in wells AM1 and AM2. The total amount of reclaimed water pumped in water supply wells is below 35%. Arrows indicate rainfall events associated with *packets of water* causing picks of reclaimed water arrival in water supply pumping wells. The travel time form infiltration basins to pumping wells is 2 years (e.g. the *packet of water* shown in the 730 days plume near the well "camping" corresponds to the second arrow in Figure 9). We expect that oscillations observed in breakthrough curves are overestimated in the model and provide a limiting worst case scenario for maximum concentration of reclaimed water reaching the water supply wells.

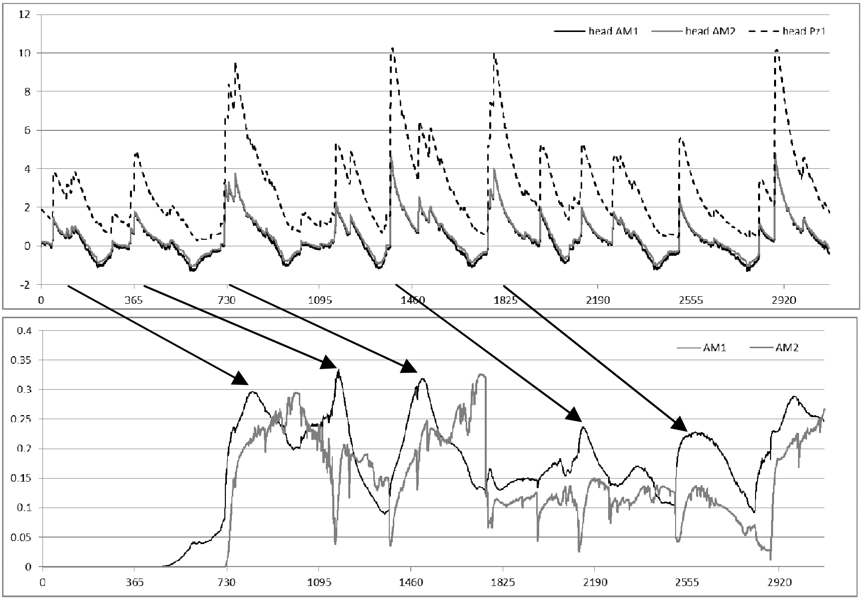

Figure 9: Top: Hydraulic heads in wells Pz1, AM1 and AM2 (m.a.s.l.). Bottom: Dilution rates in wells AM1 and AM2 (Breakthrough curves of reclaimed water).

Global mass balance is given in Table 1 for reclaimed water and in Table 2 for total water. The transport simulation (imbalance in Table 1) is less accurate than the flow simulation (imbalance in Table 2) but the amount of reclaimed water discharged to the sea is very low in any case. Flow within the aquifer is highly transient and it is controlled by both high pumping rates during summer and rain events taking place in autumn and/or spring. Pumping rates during summer (reaching up to 2500 m3/day) are above annual mean recharge due to rainfall (644 m3/day areal recharge plus 1430 m3/day lateral inflow from hill slope) which means that (part of the water) extracted in summer must come from aquifer storage.

Table 1: Global mass balance of reclaimed water after 3100 days

Total volume of reclaimed water infiltrated in the aquifer	**+620000 m^3**
Extracted in pumping wells	**-388000 m^3**
Not captured in wells and discharged to the sea	**-32000 m^3**
Remaining stored in aquifer	**-149000 m^3**
Imbalance	**-51000 m^3**

Table 2: Global mass balance of total water after 3100 days

Areal recharge	**+2 Hm^3**	**644 m^3/day**
Lateral inflow from hill slope	**+4.42 Hm^3**	**1430 m^3/day**
Extracted in pumping wells	**-2.76 Hm^3**	**890 m^3/day**
Discharged to the sea	**-3.66 Hm^3**	**1180 m^3/day**
Imbalance	**0.004 Hm^3**	**1.3 m^3/day**

5 Conclusions

We developed a numerical model to analyse the migration of reclaimed water infiltrated in the alluvial aquifer in El Port de la Selva. Despite a number of simplifying assumptions, the numerical model is capable of simulating aquifer response to rainfall events and pumping in water supply wells with reasonable accuracy.

Water availability during the summer season depends on aquifer storage and the stored water is incorporated in the aquifer in just a few events of heavy rain during spring and/or autumn. These rain events also have a major influence on the migration of reclaimed water downstream the infiltration ponds. The model is capable of computing the breakthrough curves of reclaimed water in water supply wells. Estimated travel time from infiltration ponds to pumping wells is 2 years with the initial set of model parameters used here (porosity 30%, longitudinal and transverse dispersivity 5 m and 0.5 m). Dilution rate oscillates considerably with time but remains below 35%. We expect travel time to be highly sensitive to porosity values used in the model but estimates obtained here (730 days and 1000 m travel distance) are more than 1 order of magnitude larger than the minimum residence times reported in the literature for effective SAT treatment. Results obtained so far are on the safe side since a minimum residence time of 60 days is suggested in CDPH (2011) while others (Bouwer 1988; Asano and Cotruvo, 2004) indicate at least 50-100 m travel distance and around 6 months residence time.

Using the model, it will be possible to test the sensitivity of travel time and dilution rates to several aspects such as infiltration rates, rainfall scenarios, pumping rates in water supply wells and (uncertain) aquifer parameters such as porosity and hydraulic conductivity.

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Combining treatment of reverse osmosis concentrate and biomass production at the Torreele reuse facility

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Abstract

Since 2002 the Intermunicipal Water Company of the Veurne Region (IWVA) produces infiltration water for indirect potable re-use through artificial recharge. At the Torreele facility the secondary wastewater effluent from the wastewater treatment plant of Wulpen, is treated using a combination of membrane techniques being ultrafiltration (UF) as the pre-treatment for reverse osmosis (RO). The produced RO filtrate is pumped to the dune area of St-André where it recharges the dune aquifer. Since 2003 63,7% of the groundwater extracted at St-André was recharged and thus re-used resulting in a reduction of the 'natural' groundwater extraction. This enabled sustainable groundwater management in this dune area with high ecological interest and improvement of the drinking-water produced at St-André.

Both UF and RO produce wastewater, respectively UF backwash water and RO concentrate. From 2003 until 2009 a 9 m² subsurface flow constructed wetland (Phragmites) was used to investigate the possibility to reduce the nutrient content of the mixed discharge water. The nitrogen content reduced by 30%; organic content (TOC, COD) was removed only partially and phosphorous content did not change (Van Houtte et al., 2011).

Since 2007 willows have been tested. The objective not only was impact mitigation and reduction of costs (discharge fee) but also biomass production by short rotation coppice (SRC). The focus was also on treatment of RO concentrate as IWVA planned to reuse UF backwash water using sand filters.

In February 2011 a test field of 28,6 m² containing 70 willows of 9 different species was installed. This field is approximately 3 m wide and 9,5 m long. It contained calibrated sand; the sand bed being 70 cm thick (Berquin, 2011, Ghyselbrecht et al., 2012). The willows were put in rows at a distance of 45 cm; each row lies 70 cm from the other.

The initial feed flow was 500 l/h. Based on the results of biomass production, resistence to salinity and experience with resprouting after harvesting, since beginning 2014 only 3 species are used. In 2013 the length of the field was reduced to 8,7 m and the flow was 250 l/h. The test is part of the DEMOWARE project, WP1 'Demonstrating innovative treatment processes and reuse scheme operations'.

The results of 2014 were consistent with those of the previous years. For nitrogen the removal improved with the years and based on 23 samples the average removal in 2014 was 26,2% (median 28,5%). Phosphorous removal was in the same order with an average of 27,1% and a median of 32,6%. Initially the phosphorous removal amounted more than 40% but this was probably due to the use of old sand from rapid sand filtration used to remove iron from groundwater. COD removal was 6,5% on average and zinc was removed by 19,9%.

There are also seasonal variations. Nitrogen is also slightly removed in winter but the best removal is achieved during the summer.

The average weight of the 2 species that are currently most abundant in the test field was 8,9 and 9,7 kg/sprout after 2 years of growth (harvested December 2012). Also analysis of leaves are performed.

The paper and presentation will focus on the results of 2014 and 2015. It will be interesting to see if nitrogen removal will still improve in 2015 compared to previous years. Using the most recent results an economic evaluation will be made to see if willow treatment of RO concentrate is feasible. It could contribute to the concentrate problem, mitigating the impact on the receiving water body, but it could also help mitigating the climate impact as SRC is a carbon dioxide neutral energy source.

1 Introduction

In the first 13 years of operation 25 million cubic meters of reused water, produced at the Torreele facility, were recharged into the dune area of St-André representing 38% of the total drinking-water demand in that period. This combination of water reuse with infiltration enabled the Intermunicipal Water Company of the Veurne region (IWVA) to reduce the groundwater extraction by more than 50% resulting in a higher water table in the dunes and consequently enhanced natural values. As the water table rises it is also a preventive and pro-active measure against the expected effects of climate change (Van Houtte and Verbauwhede, 2013).

This kind of wastewater effluent reuse, IWVA treated the effluent from a nearby wastewater treatment plant, is possible because reverse osmosis (RO) membranes were used. It is the best available technology when drinking-water is at stake. In general the resulting water is of better quality compared to conventional treatment regarding the total dissolved solids (TDS), total organic carbon (TOC) (Le Corré et al., 2012) and trace elements and contaminants (Ernst et al.,2012). The criteria of all regulated microbiological and chemical constituents are met (Le Corré et al., 2012) and pathogens are removed (Levantesi et al., 2010).

At the Torreele facility, ultrafiltration (UF) is used prior to RO as it removes bacteria and suspended solids from the water and thus being a good pretreatment for RO.

The process is based on multiple barriers although according to Le Corré et al. (2012) the role of dunes passage is limited in this case : *'…the level of pre-treatment prior to infiltration ensuring robust, reliable treatment of effluent to very high quality standards prior recharge combined with the 35 days retention time leaves little opportunities for quality improvements during soil aquifer passage.*' The combination of water reuse combined to infiltration not only allowed sustainable groundwater management but proved successful in providing water with high quality standards (Van Houtte and Verbauwhede, 2008, 2013).

Both UF (35%) and RO (65%) produce concentrate. The quality of UF backwash water is almost the same as the treated effluent except that it contains the suspended solids that were removed and thus more concentrated. Beginning 2016 the IWVA will start treating the UF backwash water with continuous sand filtration. The filtrate of this process (90 to 95% of backwash volume) will be pumped to the inlet of the plant; the backwash water from the sand filtration, containing high amounts of suspended solids, will be further treated. In that way the amount of discharged water will be reduced by 30% as only RO concentrate will remain to be discharged.

This RO concentrate contains elevated concentrations of all constituents removed. Currently it is discharged to an adjacent canal together with the UF backwash water. RO concentrate is often a barrier in the realization of a reuse project but here the canal is brackish and drains to the sea. Hence the impact of this discharge is low. Notwithstanding this low impact since long IWVA studies ways to minimize the impact of this drainage (Van Houtte et al., 2012). Moreover IWVA is taxed for this discharge and the main impact comes from the high nutrient level. Reducing the amounts of nutrient would reduce the discharge fee substantially.

The first test started in 2003. A subsurface flow constructed wetland with Phragmites treated the mixed concentrate, thus UF backwash water and RO concentrate. Short test feeding only RO concentrate learned that Phragmites could not tolerate the salt content.

Since 2007 tests were performed using willows (Berquin, 2011, Van Houtte et al., 2012, Ghyselbrecht et al., 2012) and these tests resulted in the final set-up that will discussed here. The set-up of the test is based on the principles of short rotation coppice (SRC).

2 Short rotation coppice

Short Rotation Coppice (SRC) is a crop of wooden species planted at very high density with the intention to produce wood. ‘Short Rotation’ reflects to the frequency of harvesting which is in the order of 2 to 4 years. The biomass produced is considered a renewable energy source. It can be used for heating.

The removal efficiency of willows (Salix) for wastewater treatment has been investigated and demonstrated in Sweden, Poland, Denmark and the United Kingdom (Hasselgren et al., 1998 and Perttu at al., 1999). *Salix* as a fast-growing tree species has several advantages over herbaceous species, such as a deeper root system, high productivity and transpiration activity; it represents a promising resource in mitigating impacts of environmental degradation (Wani et al., 2011). In Sweden in some places wastewater is treated using willows. Willows are also used for phytoremediation to clean or mitigate hazardous waste/pollution (Nissim et al., 2014).

Also Short Rotation Coppice (SRC), referring to biomass production systems for energy purposes using fast-growing tree species, having the ability to resprout from their stumps after being harvested at short intervals (2–4 years) (Dimitriou et al., 2010), is considered an energy-efficient carbon conversion technology to reduce greenhouse gas emissions (Styles and Jones, 2007).

3 Set-up of the willow test

A test field with a surface area of 3 m wide, 9,5 m long and 70 cm deep was filled with calibrated quartz sand (0,7 to 1,25 mm) from an old sand filter (table 1). The grains had iron oxides on the outside. The feed of concentrate was at surface level on one side of the field and the effluent was gathered at the bottom of the sands at the other end of the test field (fig. 1). This means that the concentrate flowed horizontally from one side to the other; no 'dead' zones were present.

Table 1. Characteristics of the willow test field

Lenght 9,55 m; 8,70 m since August 2013 ***Width 3,00 m*** ***Depth 0,7 m; filled with calibrated sand (0,7 -1,2 mm)***	***Surface 28,3 m²; 26,1 m² since August 2013*** ***Volume 19,8 m³; 18,3 m³ since August 2013***
Feed flow 500 l/h (2011 – 2012) 250 l/h (2013 – 2015)	***Quality : RO concentrate***

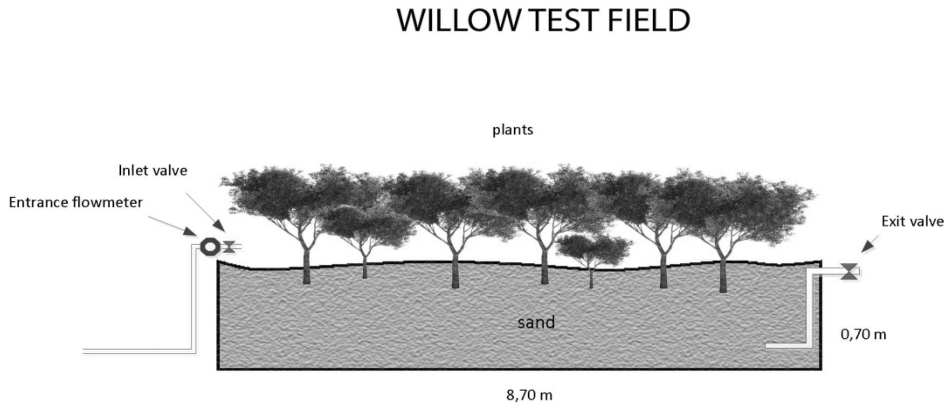

Figure 1. Scheme of willow test field

Initially, at the start of this test in 2011, 70 plants (9 different species) were randomly placed in rows; each row being 70 cm apart with plants in a row at 50 cm distance (Berquin, 2011, Van Houtte et al., 2012, Ghyselbrecht et al., 2012). Due to unexpected works the field had to be shortened (8,7 m) in the summer of 2013; as a consequence several pants suffered from drought and had to be replaced. As part of the DEMOWARE project, WP1 'Demonstrating innovative treatment processes and reuse scheme operations', the test continued from 2014 onwards but with plants from only 3 different species. All plants were cut the 14th of February 2014. Two species were a variety of Salix x rubens var. Basfordiana, Dutch cultivated types, and one was a Salix nigra clone from the United States. This test will continue until the end of 2015, but to present many results are already available.

At the end of 2015 the experiment will be evaluated in several ways :

- Evaluation of growth of different plants and species;
- Chemical analysis of influent (RO concentrate) and effluent from the test field;
- Composition of the leaves;
- Weight of biomass of the plants.

4 Growth of the plants

Initially in 2010 10 species were tested and after the first year of experiences with the test field 6 species remained at place (Berquin, 2011). Three years later, at the start of the DEMOWARE project, at the exception of 2 plants only 3 species remained. After cutting of the plants in February 2014, the Salix rubens clones started resprouting again. The Salix nigra clones suffered after cutting and several plants had to be replaced. The current height of the plants, in its second growing season, amounts 2,5 to 3 meters which is the same height as in the first period of growth (Van Houtte et al., 2012).

Based on the first experiences, where the selected species obtained the highest weight, respectively 11,4 9,7 and 8,9 kg compared to the average of 8 kg/plant, we can expect good results for the plants present in the field now. The plants will be harvested by the end of December enabling evaluation of future yield when establishing a full-scale plant.

In conventional SRC projects, where 15.000 stools per hectare are common, willow crops can produce 10 to 15 tons of dry mass/ha/year. Based on the current results it can be expected that the willows grown on RO concentrate will produce more.

5 Nutrient removal

As nutrients contribute to eutrophication of surface waters and as in the Torreele case nutrients also have the highest contribution in the discharge fee, their removal was an important objective when starting experiments treating the discharge water with natural systems. The experiments from October 2003 until 2009 using a subsurface flow reed bed for the treatment of both UF backwash water and RO concentrate showed a reduction of nitrogen content by 30%; organic content (TOC, COD) was removed only partially and phosphorous content did not change (Van Houtte et al., 2011). The first experiments with willows, but then only treating the RO concentrate, not only showed nitrogen removal but also removal of phosphorous : a promising result.

In 2011 and 2012 the flow over the willow field was 500 l/h and this resulted in average removal rates of 10,2% for COD, 10,3% for total nitrogen, 28,6% for total phosphorous and 23,7% for zinc. During 2013 the flow was lowered to 250 l/h and this resulted in higher removal rates for COD (13,1%) and total nitrogen (22,7%). The average removal for phosphorous (25,1%) and zinc (23,5%) was in the same order. The influent, thus RO concentrate, is saturated with oxygen which is absent from the effluent.

Since beginning of 2014 samples from the in- and effluent of the willow field were taken every two weeks. The samples are taken with a delay of approximately one day, the time needed for the water to pass the willow field. This was calculated taking into account the volume of the test field and checked using the variation of conductivity. The main parameters analyzed were COD, total nitrogen, total phosphorous and zinc. Sampling is performed during 18 hours with an automatic sampler; all analysis are performed by accredited labs.

In table 2 and 3 the results are shown for 2014 and 2015. The conductivity of in- and effluent is in the same range which means that the results of the samples are a good indication for the performance of the willows. The average flow over the field remained 250 l/h.

The following conclusions can be made :

- The removal of COD is low (around 10%) probably because the COD that remains in the effluent of the wastewater treatment plant is non-biodegradable;
- The removal of total nitrogen seems to improve every year and achieved 35%; even in winter time (fig.) nitrogen is partly removed; according to Aronsson (2001) this is due to the perennial root system; the growing season is defined as the period with temperatures greater than 5°C (the temperature of the RO concentrate is always above 5°C when entering the field);
- The removal of total phosphorous is constant over the years; during winter the phosphorous content of the effluent can be higher compared to the influent (fig) probably due to leaching;
- The removal of zinc is constant over the years.

Table 2. Characteristics of the influent and effluent samples of the willow test field and resulting removal efficiencies in 2014 (23 samples)

	Influent	Effluent	Removal based on yearly average	Average removal rate
Conductivity (µS/cm)	5.509 ± 1.210	5.509 ± 1.007		
pH	8,0 ± 0,1	8,0 ± 0,1		
COD (mg O_2/l	99 ± 17,2	92 ± 16,1	7,2 %	6,5 %
Nitrogen (mg N/l)	26,1 ± 7,6	18,7 ± 4,1	28,5 %	26,2 %
Phosphorous (mgP/l)	4,1 ± 1,3	2,8 ± 0,5	32,6 %	27,1 %
Zn (mg/l)	51,7 ± 12,9	40,8 ± 10,1	21,0 %	19,9 %

Table 3. Characteristics of the influent and effluent samples of the willow test field and resulting removal efficiencies in 2015 until early September (16 samples)

	Influent	Effluent	Removal based on yearly average	Average removal rate
Conductivity (µS/cm)	4.808 ± 570	4.794 ± 535		
pH	8,0 ± 0,1	7,9 ± 0,1		
COD (mg O_2/l	120 ± 15,3	107 ± 15,7	11,4 %	12,4 %
Nitrogen (mg N/l)	31,4 ± 11,3	20,1 ± 7,3	35,9 %	35,5 %
Phosphorous (mgP/l)	4,1 ± 1,8	2,7 ± 0,6	34,4 %	27,9 %
Zn (mg/l)	56,3 ± 15,3	46,3 ± 11,7	17,9 %	16,0 %

The best removal rates are achieved during the warmer season (fig 2). For the 6 samples taken in June, July and August 2015 average removal rates of respectively 46,7% and 50,2% for nitrogen and phosphorous were achieved.

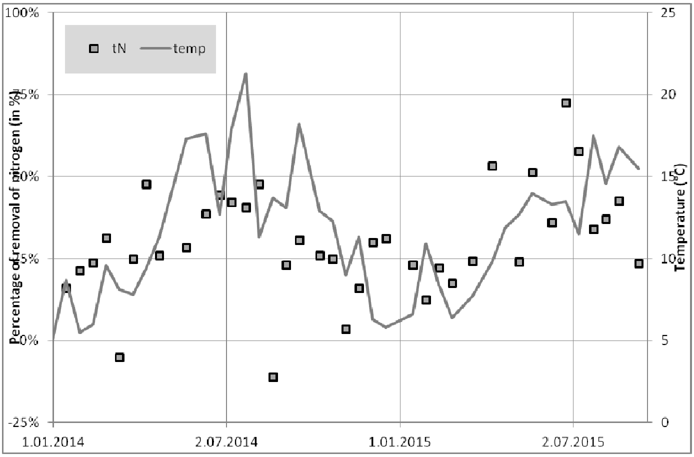

Figure 2. Removal rate in % of nitrogen by the willows

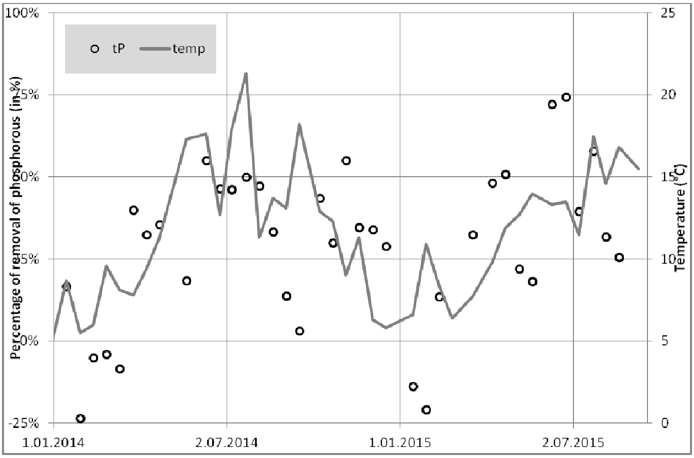

Figure 3. Removal rate in % of phosphorous by the willows

Calculation of the discharge fee showed that the extra treatment of RO concentrate using willows could save annually around 30.000 euros due to reduced concentration of nitrogen and phosphorous in the RO concentrate.

6 Plant content

In September 2014 leaves of 10 different plants were taken, dried and analyzed by the University of Ghent (Faculty of Agronomic Sciences). The results are shown in table 4 to 6.

The results from previous analysis (Van Houtte et al., 2012) showed that the total carbon content does not differ substantially for the different species and the same conclusion is applicable on the results from September 2014 (table 3). The phosphorous and nitrogen content of the leaves has a greater variation : the phosphorous content is around 2 mg P/g and the nitrogen content is around 3% (table 4). Previous analysis showed similar results for these species (Van Houtte et al., 2012). No conclusions can be made according to the position of the plants in the field : beginning or end of the field.

Table 4. Results of carbon and nitrogen analysis of dry residue

	mg P/g plant	%N	%C
avg	2,01	3,09	44,69
median	2,04	3,10	44,86
min	1,64	2,62	43,48
max	2,27	3,60	45,94

The variance of anions and cations (table 5) is greater compared to that of carbon, nitrogen and phosphorous but it is in the same order as in previous analysis, (Van Houtte et al., 2012).

The variance of metals was even greater compared to anions and cations as was the case in previous analysis but then 10 different specious were concerned (Van Houtte et al., 2012). The metal content of the leaves is low which means that it could not harm environment when biomass would be used for heating. Compared to previous research (Willwater project LIFE04 ENV/FR/320) the cadmium and lead content is below the reference levels of respectively 500 to 4.100 µg/kg DS for cadmium and 400 to 1.300

µg/kg DS for lead. It should be said that the metal content in the wastewater effluent that is treated at the Torreele facility is low as the Wastewater treatment plant of Wulpen, operated by Aquafin, mainly treated domestic wastewater.

Table 5. Results of analysis of some anions and cations

		mg/kg DS	**g/kg DS**			
	%DS	**S**	**Ca**	**K**	**Mg**	**Na**
average	27,8	4045	12,4	29,1	2,8	0,7
median	27,4	3979	12,2	29,2	2,7	0,6
min	26,1	3133	9,4	23,4	2,2	0,4
max	30,9	5224	15,9	35,0	3,3	1,6

Table 6. Results of analysis of some metals

	mg/kg DS					**µg/kg DS**	
	Al	**Cu**	**Fe**	**Mn**	**Zn**	**Cd**	**Pb**
avg	44,1	3,6	125,2	116,0	66,9	40,3	432
median	45,8	3,6	114,0	118,5	58,1	34,5	426
min	30,2	2,5	84,5	68,4	22,5	26,8	345
max	55,4	4,9	257,0	198,0	143,0	97,6	519

7 Conclusion

The Intermunicipal Water Company of the Veurne Region (IWVA) achieved sustainable groundwater management of its dune water catchment by integrating water reuse and artificial recharge. The membranes used assure a high quality water but the inconveniencet is the production of UF backwash water and RO concentrate that need to be discharged. In 2016 IWVA will start reusing UF backwashwater using sand filtration leaving only RO concentrate to be drained.

Since 2003 IWVA experiments natural treatment for discharge water. Since 2011 a willow test field is operational for the treatment of only RO concentrate. Willows proved to be capable to treat waters with high salinity. In 2014 and 2015 this test was part of the DEMOWARE project. After cutting in February 2014 the plants resprouted and grew fast again, especially the Salix x Rubens var. Basfirdiana clones, reaching heights of up to 3 m. Analysis of the in- and effluent of the willow field confirmed preliminary results. In 2015 nitrogen and phosphorous is removed for 35% on average. If this willow treatment would be built on full-scale it would mitigate the effects of discharging this water into the environment and save annually around 30.000 euros of discharge fees.

Besides, this way of producing biomass prevents CO_2 release as it is a CO_2 neutral way of producing energy and thus mitigates the effects of climate change.

Acknowledgment

The author wants to thank Pierre Van Peteghem of INBO. He did put the plants to our disposal. The recent research was made possible by grants from the European Commission within the FP7-programme as this test was part of the DEMOWARE project (FP7-ENV-2013-WATER-INNO-DEMO). Off course all colleagues of IWVA should be mentioned as we all need a team to achieve something.

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Wastewater reuse for industrial applications in cooling towers

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Dow Water & Process Solutions

Abstract

This study describes the reuse for the local petrochemical industry of reverse osmosis permeate water obtained from El Camp de Tarragona Advanced Water Reclamation Plant (CTAWRP) located in Vila-Seca (Catalonia, Spain). Reusing treated tertiary wastewater results of utmost importance since it enables liberating hydraulic stress from the Spanish Ebro River. This is achieved by blending up to 40% of reused water into river water so that it can be used by the cooling towers as make-up water. The blending that started at 15% is able to show a stable operation during the whole period of time. This change is proven to neither have impact on Legionella Pneumophila or aerobic bacteria growth nor on scaling or corrosion phenomena appearance. This has not only a positive impact to the environmental, but also using permeate water enables increasing the concentration cycles in the cooling towers up to more than 7 times from the original 4 ones with the corresponding reduction of the amount of chemicals consumed in cooling water treatment to prevent scaling and corrosion events. This project is framed under the European Research and Development funded DEMOWARE Consortium, led by CTM (Centre Tecnológic de Manresa), under the FP7-ENV-2013-WATER-INNO-DEMO Call.

1 Introduction

The Tarragona region is a growth area that is water stressed as the Ebro River water is used many times before reaching the sea. The municipalities in the region require more of this river water to enable their growth.

Site and regional water supply of the Petrochemical Complex in Tarragona, Spain, is sourced from the Ebro River. AITASA is the company responsible of distributing industrial water in the Tarragona area.

The large Petrochemical Complex in Tarragona has sufficient water rights, which is mostly used in evaporative cooling towers that control the petrochemical process temperatures. In the graph below (Figure 1) can be found the water rights percentage for both municipalities and Industries:

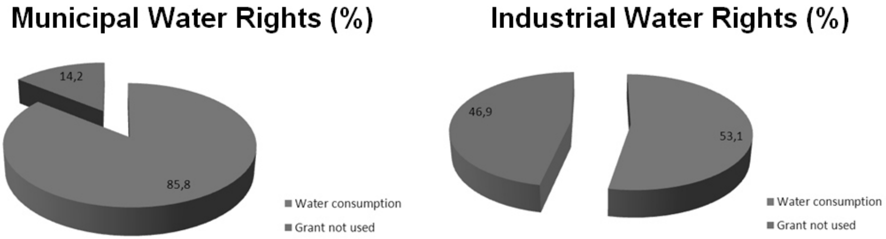

Figure 1: Water Rights used in the Tarragona Area

Ebro River water is relatively high in salts and is generally of consistent quality with some seasonal variability (see attached graph Figure 2).

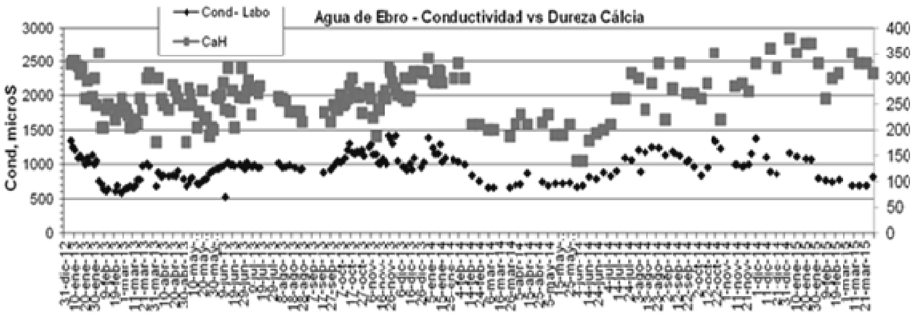

Figure 2: Ebro River water seasonal variability

In order to free up river water rights for municipal use, a project was started to find an alternative water source for the industrial petrochemical complex.

This proposed water reuse project, embodied by the Camp de Tarragona Advanced Water Reclamation Plant (CTAWRP), that VEOLIA and AITASA operates in Vila-Seca (Catalunya – Spain-), will free up existing raw industrial water rights to meet local municipal demand growth, and will decrease the water stress to Ebro River. The CTAWRP is fed with the secondary effluent water coming from Wastewater Treatment Plants (WWTP) of Vila-seca, Salou and Tarragona. This plant uses Actiflo clarification technology, two steps filtration followed by two pass DOW FILMTEC™ reverse osmosis that produces relatively high quality, low hardness and low salts water [Salgado et al., 2013 ;Sanz at al., 2015].

As the incumbent cooling water treatment supplier, Nalco Champion started a management of change program to ensure the changing water qualities could be utilized to maximum effect. The long term goal is to use 800m3/h of RO permeate as cooling tower make up a the various petrochemical sites to free up the water rights on the river Ebro for municipal use.

2 Methods

<u>Camp de Tarragona Advanced Water Reclamation Plant (CTAWRP)</u>

El Camp de Tarragona Advanced Water Reclamation Plant (CTAWRP) treats 19,000 m3/d of permeate water. This water is used for blending water with Ebro River water in order to provide make-up cooling water for the Tarragona Petrochemical Complex Plants.First pass uses DOW FILMTEC™ BW30XFR-400/34i extra fouling resistant membranes, while second pass uses DOW FILMTEC™ LE-440i low energy membranes. Figures 3 and 4 show the CTAWRP diagram and a detail picture [Salgado et al., 2013].

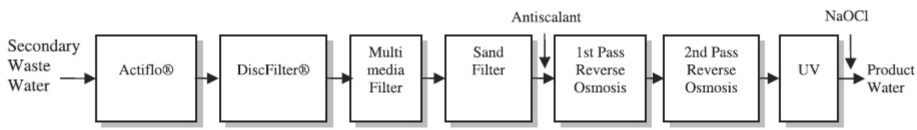

Figure 3: El Camp de Tarragona Advanced Water Reclamation Plant (CTAWRP) diagram

Figure 4: El Camp de Tarragona Advanced Water Reclamation Plant (CTAWRP) detail picture

Cooling Towers make up water

The objective was to initially supply reverse osmosis water through a dedicated line to the Dow Chemical Ibérica Tarragona (DCI) North petrochemical production complex (Ethylene Cracker), located in the municipality of La Pobla de Mafumet (Tarragona – Catalunya – Spain -). There, river water is blended with RO permeate coming from WWTP to provide make up water. Figure 5 shows the picture of the cracker cooling tower.

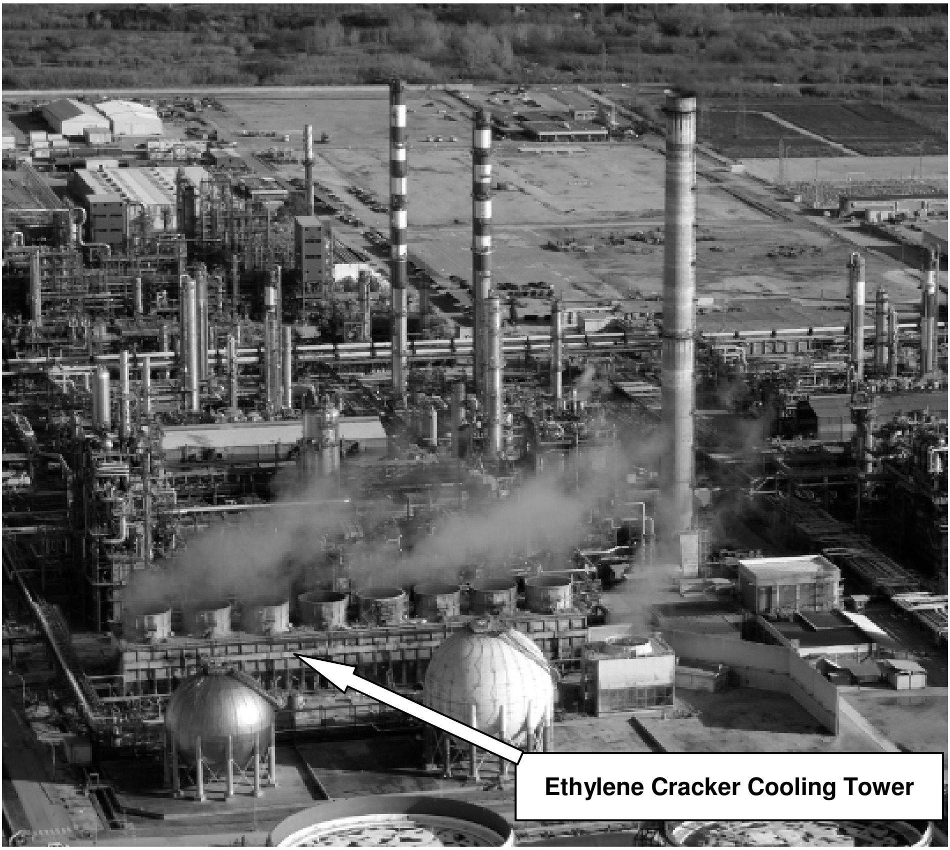

Figure 5: Cracker Cooling Tower.

For the DCI south production complex (Poliolefins and Polyols/Polyglycols units), the current plan is to supply the two water sources (Ebro river raw water and RO permeate) through existing parallel headers. One header would supply blended EBRO and RO water at a normal ratio of up to 40% RO permeate. The second header would supply unblended Ebro water. Without a network isolation plan, the two waters would blend in the site piping network. In later stages the RO permeate is expected to be as much as 90% or more of the total water supply both sites.

Water quality

The RO Permeate water quality from CTAWRP is much lower in scaling tendency than the Ebro water as shown in Table 1, and could therefore be use at higher cycles of concentration than the current 4 applied in the cooling tower. Based on treatment simulations the cooling tower can reach 8 cycles of concentration with good corrosion control using a dual cathodic program. Higher cycles of concentration lead to lower blow down and significant water savings. However the water is higher in compounds that allow microbial growth (ammonia, phosphate and organic carbon), therefore good microbiological control is essential. Also the buffer capacity is limited, and chlorides are relatively which could lead to corrosion. Therefore 8 cycles are deemed optimal even though the low scaling tendency would allow far higher cycles.

Table 1: Water quality comparison (Ebro river vs. CTAWRP).

Compound	Ebro River	RO Permeate
Conductivity	950 µS/cm	19 µS/cm
Cl	95 mg/L	2.94 mg/L
$CaCO_3$	260 mg/L	< 0.1 mg/L
SO_4	160 mg/L	0.0167 mg/L
NH_3	0.1 mg/L	< 0.8 mg/L
PO_4	0.1 mg/L	< 0.002 mg/L
TOC	1.2 mg/L	< 0.3 mg/L

Reclaimed water from the CTAWRP has an average electrical conductivity of 20 µS/cm and a TOC lower than 0.2 mg/L. Furthermore, that water quality offers the possibility for its use as feed water for demineralization processes by ion-exchange resins. In June 2014, a satellite water demineralization facility went into operation within the petrochemical park to produce 30 m3/h of highly demineralized water (0.2 µS/cm) for boiler feed water, using an ion-exchange process and reclaimed water supplied from the CTAWRP.

Based on Nalco experience the main challenge using this reused water as cooling tower make up are:

- Highly corrosive water:
  - mild steel corrosion due to lack of buffer capacity in the presence of Cl and oxygen
  - low calcium prevents normal inhibition mechanisms
  - copper corrosion due to ammonia

- Microbial activity:
  - microbiological growth due to high nutrients and organic content content
  - chloramine formation lowering biocide activity;

- Highly variable make up water:
  - High cycles possible due to low salt content
  - Cycles limited by leaks, upsets, etc. (quick variation in cycles with a leak)

Nalco R&D ran a set of 22 bench top pilot cooling tower tests to evaluate the effects of changing water quality on the cooling tower operation. These tests showed that good monitoring and control of the process parameters and chemical treatment would enable the effective use of RO Permeate at high cycles of concentration.

3 Results

Ethylene Cracker Cooling Tower Operation

The Cracker cooling tower ran on 100% Ebro river water at 4 cycles prior to the gradual change to 160 m^3/h of RO permeate. The RO make up goes up in 3 different steps; initial step is between 40-60 m3/h (15%); then moves up to 100 m^3/h (25%) to finally reach 160 m^3/h (40%).

The new water quality allows the cooling tower to be operated at 7 cycles of concentration in summer when ambient temperatures allow high evaporation rates. In winter ambient conditions do not allow the higher cycles. An investment is needed to redirect an uncontrolled blowdown to the cooling tower basin so the optimum theoretical cycles of 8 can be reached in future. See Table 2 and Figure 6.

Table 2: Water Quality vs. Cycles of Concentration.

Compound	Ebro	RO Permeate	Ebro x 4	Permeate x 7
Conductivity	950 µS/cm	19 µS/cm	3800 µS/cm	135 µS/cm
Cl	260 mg/L	2.94 mg/L	1040 mg/L	21 mg/L
$CaCO_3$	95 mg/L	< 0.1 mg/L	380 mg/L	< 1.0 mg/L
SO_4	160 mg/L	0.0167 mg/L	640 mg/L	0.07 mg/L
NH_3	0.1 mg/L	< 0.8 mg/L	0.4 mg/L	< 5.0 mg/L
PO_4	0.1 mg/L	< 0.002 mg/L	0.4 mg/L	< 0.02 mg/L
TOC	1.2 mg/L	< 0.3 mg/L	4.8 mg/L	< 2.0 mg/L

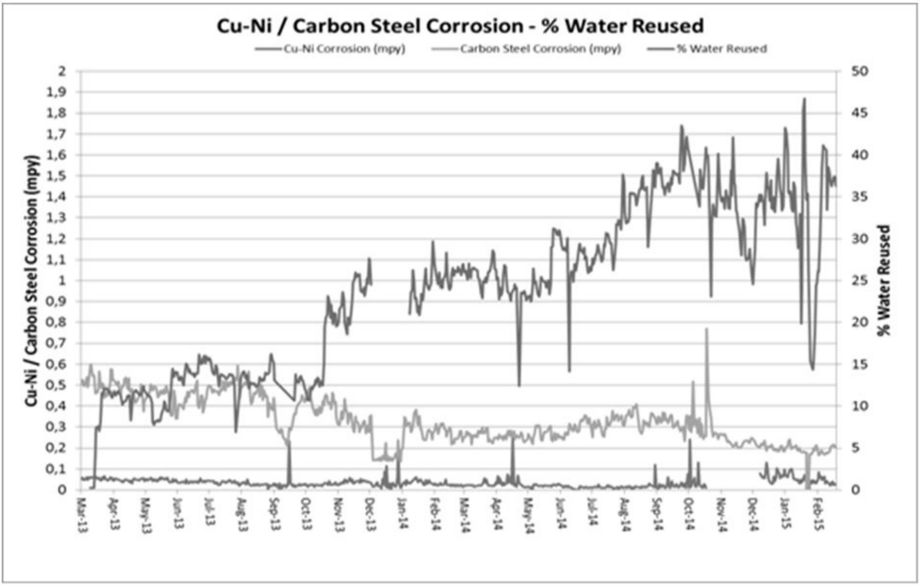

Figure 6: Reused Water – Percentage and Flow Rate

With this cycles increase in summer due to better evaporation, a reduction of total make up water of 110.5 m^3/h (22%) has been achieved as well as a reduction in sewage of 76.0 m^3/h (49%). This reduction of water use in summer coincides with high municipal demand.

Special care should be taken into account when increasing the concentration cycles since phosphate and nitrate concentration could be a source of potential biofouling in the cooling towers.

Ethylene Cracker Cooling Water System Performance.

The impact on microbial growth and corrosion was controlled and monitored using 3D TRASAR® Technology for cooling water. The 3D TRASAR® unit monitors and controls the chemical treatment to control scaling and corrosion based on on-line measurements, based on the product need. Depending on the make-up water changes (leaks, upsets, reused water availability…) the 3D TRASAR® unit adjusts the rate of addition of the treatment chemicals. The alarming service allows notification by email, text and via the web for virtually instant notification when the parameters reach critical levels, as an added security.

Ethylene Cracker Cooling Water System (Scaling & Corrosion Performance).

Based on the ASTM corrosion guidelines as well as Dow requirements (see Table 3) the carbon steel corrosion rate is below 1 mpy and for copper-based alloys below 0.1 mpy. Figure 7 shows the Nalco Champion 3D TRASAR® corrosion probe readings, showing that the corrosion is controlled within range after the reused water was added.

As a result, the amount of chemicals needed in the cooling towers to control potential scaling and corrosion events will be reduced given the better quality of the treated water (compared to the fresh water).

Table 3: Guidelines for Quantitative Classification of General Corrosion Rates

Corrosion Rate in mpy (≈mm/y)		Description
Carbon Steel	**Cooper-Based Alloys**	
< 1 (< 0.03)	< 0.1 (< 0.003)	Negligible or Excellent
1 – 3 (0.03 – 0.08)	0.1 – 0.2 (0.003 – 0.005)	Mild or Very Good
3 – 5 (0.08 – 0.13)	0.2 – 0.3 (0.005 – 0.008)	Good
5 – 8 (0.13 – 0.20)	0.3 – 0.5 (0.008 – 0.013)	Moderate to Fair
8 – 10 (0.20 – 0.25)	0.5 – 1.0 (0.013 – 0.025)	Poor
> 10 (> 0.25)	> 1.0 (> 00.25)	Sever to Very Poor

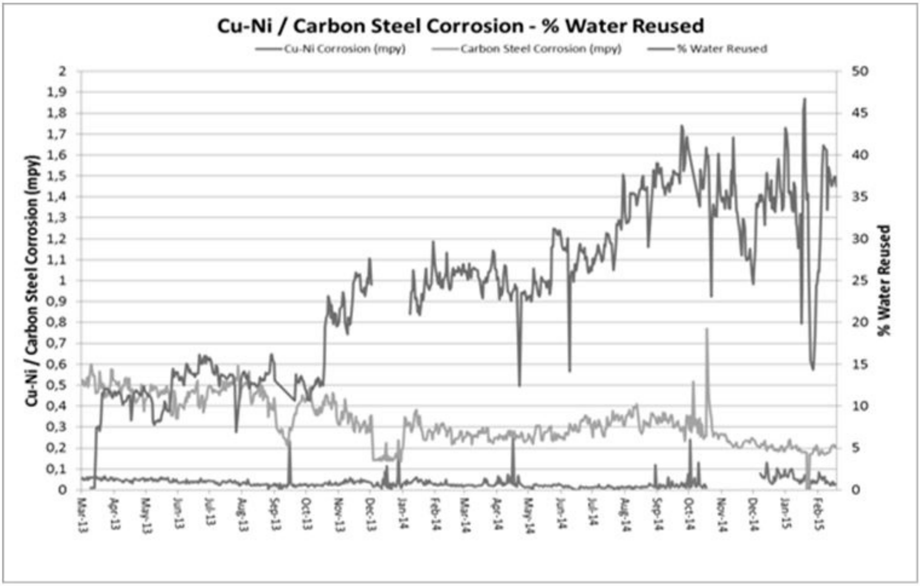

Figure 7: Corrosion vs % Water Reused

<u>Ethylene Cracker Cooling Water System (Biological Growth Performance)</u>

The tertiary treatment of the waste water treatment plant in combination with the VEOLIA Actiflo and DOW FILMTEC™ reverse osmosis technologies minimize the organic content and nutrients reaching the cooling tower. Therefore the typical (bio)fouling observed with the use of treated municipal wastewater is greatly reduced. Still the organic content and nutrient levels are higher than in river water and the analytical routine has been updated with ammonia analysis at every increase in RO water and Total Organic Content (TOC) is being done in a weekly basis.

All the ammonia results have been close to zero as the ammonia is striped out in the tower fill.

As can be seen in the Table 4 the aerobic bacteria count is on spec (< 10,000 UFC/ml as legal specification to Legionella control) during the period adding reused water. In the period under consideration no Legionella Pneumophila count has been detected in the ethylene unit cooling tower.

Table 4: Organic content and nutrients compared with aerobic bacteria adding reused water.

	River Water (100%)	River Water (60%) + Reclaimed Water (40%)
Cooling Water NH_3	0.05 mg/L	0.03 mg/L
Cooling Water TOC	19.3 mg/L	21.0 mg/L
Aerobic Bacteria	<10,000 UFC/mL	<10,000 UFC/mL

Microbiology analyses obtained from the water used in the cooling towers are performed in an accredited external laboratory. The analyses show no presence of aerobic microorganisms and legionella bacteria since starting to use blending of reused water with river water. Therefore, all analyses performed showed an aerobic microorganisms concentration below 10,000 UFC/mL and a legionella concentration below 40 UFC/mL. These results fall under the detection limit of the analytics.

4 Conclusions

This paper shows that reclaimed water can be used in the industry instead of pre-treated river water. This has a positive impact in the environment as it does not hydraulically stressing the rivers. Moreover, it allows additional benefits such as being able to operate at higher concentration cycles in the cooling towers.

Stable operation of the cooling tower has been achieved and demonstrated since starting to use to blending of reclaimed water as make-up water in the Dow Tarragona Ethylene Cracker Cooling Tower.

The careful management of changing water chemistry in the Dow Tarragona Ethylene Cracker Cooling Tower enabled the use of 160m3/h (nearly 40% of the make-up feed) of RO permeate with minimum impact on corrosion and microbial growth. Depending on the season this frees up more than 200 m3/h of water rights for the municipality. The blowdown was reduced by 76 m3/h the which is a 49% reduction in discharge from the cooling tower.

The 3D TRASAR® Technology allows to run at higher cycles of concentration by adjusting the chemical treatment automatically when the make-up water changes. Therefore it enables reducing the water consumption by keeping the corrosion in carbon steel (< 1mpy) and copper alloys (< 0.1 mpy) under control.

It can be confirmed that using reclaimed water from a Wastewater Treatment plant that has undergo a reverse osmosis filtration step present no health concerns when compared with conventional pre-treated river water.

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Improved use of carbon streams in wastewater through biotechnological processes – new approaches within the project ZeroCarbFP

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Abstract

The ‘strategic alliance’ ZeroCarbFP aims at the use of residual or waste carbon for the production of valuable products, using microorganisms instead of and/or in addition to physico-chemical processes. Within ZeroCarbFP, the subproject ‘Additives 2’ focuses on the conversion of municipal and industrial wastewater to (a) energy and (b) base chemicals (oils and fatty acids) that can be used e.g. in the lubricant industry. At the same time, the amount of residual carbon to be disposed of (e.g. as sewage sludge) is reduced. The subprogram is conducted by the Emschergenossenschaft and performed in cooperation with the BRAIN AG.

Based upon a screening campaign, the selection of microorganisms was step-by-step focused on the most promising ones which are likely able to grow in various wastewater streams and to ‘boost’ biogas production during anaerobic digestion after being grown in sewage sludge. Industrial wastewater turned out to be a suitable medium for the growth of single cell oil-accumulating organisms. Promising approaches are currently verified and optimised. This provides an excellent basis for the subsequent project phase, aiming at the process engineering of the approaches in the context of municipal and industrial wastewater treatment systems.

1 Context

Despite promising attempts and great successes in the field of renewable energy and resource protection, chemical industry still relies on finite commodities such as crude oil, both for energy production and as raw material for the synthesis of carbon-based chemicals and plastics. Since the global energy demand (and resources in general) will certainly grow, identifying alternative sources and implementing efficient, sustainable processes might be crucial for the long-term productivity of industries. This especially applies to countries that rely on imported oil and raw materials, such as Germany. Given this context, waste and residual materials – such as flue gas, process waste and wastewater – have to be considered as promising substitutes for fossil resources, especially with regard to the increasing global production of waste.

To make these ‘new’ resources accessible, a promising strategy might be the implementation of bio-based processes and applications instead of or complementary to physico-chemical ones. It is already well known that a multitude of bulk- and fine chemicals can be produced by microorganisms. Moreover, bio-based processes can be more energy- and resource efficient and thus, sustainable. Hardly surprising, the ‘biologisation’ of industry is globally proceeding.

2 The ‘strategic alliance’ ZeroCarbon Footprint

Within this context, promoting biotechnology and establishing a bio-based economy is one of the key focuses of the activities of the Federal Ministry of Education and Research (BMBF). Within its call ‘Innovationsinitiative industrielle Biotechnologie’, released in 2011, six different ‘strategic alliances’ are currently working.

One of the alliances is ZeroCarbonFootprint (ZeroCarbFP), aiming at the conversion of carbon-containing waste streams into valuable products, using so-called ***functional biomass***, i.e. microorganisms which produce target products within their metabolism (fig. 1). The project is divided into five subprograms (SP), all using different waste streams and aiming at different products. Table 1 gives an overview.

The Emschergenossenschaft (EG) is in charge of the coordination of the strategic alliance. This is consistent with the aim of the EG (as one of the largest water boards in Germany) to optimise the energy balance, to reduce CO_2-emissions and to generally use resources – such as carbon and nutrients in wastewater – in an efficient and sustainable way. To achieve these goals, the EG was and is involved in different research projects and is consequently also pursuing new developments in ‘biotechnology’ with regard to its advantages and sustainability.

The Emschergenossenschaft is additionally involved in the coordination and the activities of SP 5 ‘Additives 2’ (see table 1), aiming at the conversion of waste water (and related streams) to energy and valuable products. This is particularly interesting with regard to the energy-autarchy of wastewater treatment plants.

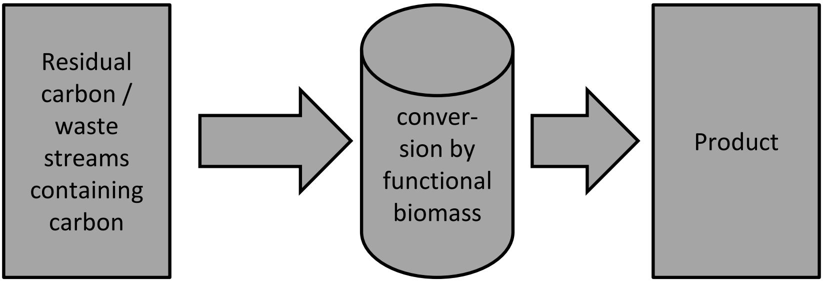

Figure 1: General approach of ZeroCarbonFootprint

Table 1: Overview of the five subprograms (SP) of ZeroCarbFP

	SP 1	SP 2	SP 3	SP 4	SP 5
Title of SP	Bioplastics	DeICE plus	Green mining	Additives 1	Additives 2
Waste stream	Waste streams; flue gas	Waste glycerine of biodiesel production	Recycling materials, landfills	Waste fats, oils, FAME etc.	Municipal and industrial Wastewater
Target products	Monomers for polymer chemistry	De-icing and cooling liquids	Sustainable ore leaching processes	High-performance additives	Single cell oils & fatty acids, energy

ZeroCarbFP is divided into three phases. Phase 1 ‘Research’ started in July 2013 and will end in June 2016. Phase 2 ‘Development’ is supposed to follow up and will soon be applied for. Phase 3 ‘Pilot testing’ is intended to start in 2019. At present, 13 partners from industry and research are involved in the alliance.

3 Subprogram ‘Additives 2’: Bridging the gap between biotechnology and wastewater treatment

Introduction

Given the fact that the power consumption of a large wastewater treatment plant (wwtp) is about 30 kWh per population equivalent and year, the optimization of the on-site energy production is a crucial aspect for wwtp operators such as the Emschergenossenschaft. At present, a substantial amount of organic carbon in wastewater and sewage sludge is already converted to energy (by anaerobic digestion), but still, a significant quantity is not yet used and has to be disposed of.

Within this context, subprogram ‘Additives 2’ aims at the conversion of this waste carbon

(a) into oil-containing biomass that can be used directly to boost the biogas production in the anaerobic digestion (product line 1; see figure 2), and

(b) into single-cell-oils (SCO; i.e. oils that are produced by single-cell organisms) that can be used as raw material, e.g. as additive in the lubricant industry (product line 2; see figure 3).

In the product lines mentioned above, two program partners are involved. The Emschergenossenschaft is in charge of the coordination of the SP. Moreover, data, mass- and energy balances, substrates, knowledge about scale-up and process engineering etc. is provided. BRAIN AG is responsible for e.g. bioprospecting, screening, selection and identification of functional biomass, microbiological analyses, fermentation of biomass, establishing analytical tools, characterization of fatty acids, evaluation of extraction protocols and strain development.

It is known that many organisms such as bacteria, yeasts and fungi are able to accumulate energy-rich lipids, especially when nutrient availability is unbalanced. Generally, nitrogen-limitation is favorable with regard to the accumulation of lipids. An example is shown in fig. 4.

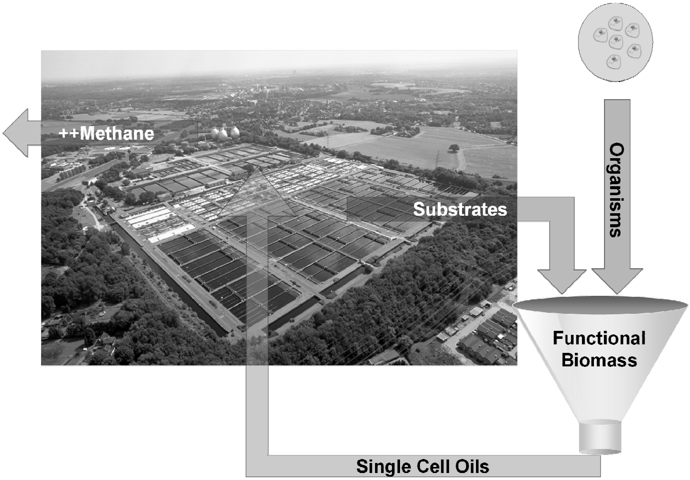

Figure 2: Approach of product line 1, aiming at the on-site production of energy

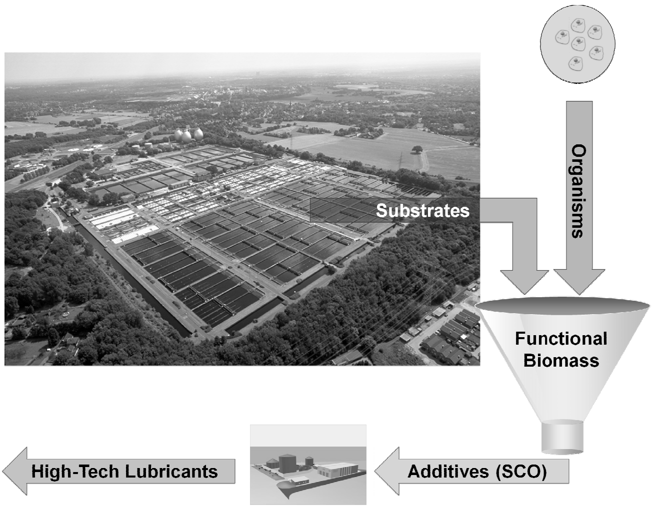

Figure 3: Approach of product line 2, aiming at the production of single-cell oils that can be used in industry

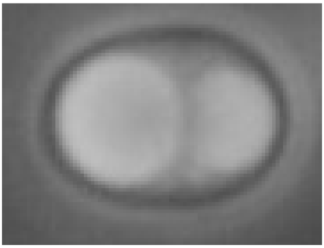

Figure 4: Accumulation of lipids (light grey areas) in a cell (Source: BRAIN AG)

Approach and methodology

To identify organisms that are able to accumulate lipids and SCO, microbial strains were selected from the proprietary BioArchive of BRAIN AG and other collections. Moreover, enrichment and screening strategies were developed to additionally identify and isolate promising microorganisms from waste- and wastewater streams.

In total, more than 200 bacteria, yeasts and fungi have been isolated and assessed. To narrow this selection, different criteria (such as lipid accumulation and risk assessment) were applied. With regard to product line 2 and the accumulation of *specific* SCO, the composition of SCO has been taken into account as well.

Based on the criteria mentioned above and after a validation step, the range of microorganisms has finally been reduced to the most promising ones.

Identification of suitable substrates for biomass growth

Product line 1

As growing media for the selected microorganisms, the following municipal wastewater- and sludge streams have been selected:

(a) digested sludge, because at present, sludge after anaerobic digestion has to be considered as waste, has to be treated and finally, disposed of;

(b) excess sludge, because it is known that the substrate is hardly degradable during ‘standard’ operation of the anaerobic digestion (so there is a great potential for new approaches); and

(c) primary sludge, because it is known that carbon contained therein is easily available for organisms.

<u>Product line 2</u>

In contrast to product line 1, product line 2 focuses not on on-site energy production, but on the production of specific SCO and lipids that will be extracted and processed for industrial use. The approach is therefore not necessarily limited to municipal wastewater and wwtp. Thus, industrial wastewater, e.g. from food industry, has been taken into account as well as growing media.

Assessment of biomass growth in selected substrates

Using microtitration plates, the growth of the selected microorganisms in these streams has been assessed in lab-scale. Microbial growth was detected by oxygen demand in combination with the turbidity of the sample and the determination of colony-forming units (CFU).

4 Results

Investigation of boost of energy production

A set of organisms potentially able to grow in the selected substrates and to accumulate substantial amounts of lipids in biomass was identified. Since it is known that lipids can easily be degraded in anaerobic digesters, it is expected that these microorganisms are able to boost biogas production significantly.

To assess biomass growth and lipid accumulation under ‘real’ conditions, microorganisms are grown in lab-scale bioreactors (1.000 ml). Microbiological analyses have shown that the quantity of functional biomass increased by a factor of 50 to 100 during one day of fermentation. First results also indicate a positive effect on the biogas production. To verify these promising results, further investigations are underway, taking the amount of biogas, its composition and the energy balance of the whole process into account as well.

Accumulation of specific SCO

As for product line 1, a set of organisms potentially able to grow in the selected substrates (wastewater originating from industry and/or municipal wwtp) was identified. With regard to the intended production of *specific* SCO, the composition of accumulated SCO as verified by GC-MS-analysis seems to be promising for further biocatalysis and use in industry. Functional biomass will subsequently be grown in bioreactors as well, aiming at the provision of a sample of SCO that can be analyzed by the lubricant industry.

To improve biomass growth and SCO accumulation, medium composition is optimized. Within this context, it is currently evaluated if a nutrient-rich substrate – e.g. from a municipal wwtp – can be used for the growth phase and a carbon-rich substrate – e.g. from food industry – to enhance SCO-accumulation after growth. An extraction protocol to separate SCO from biomass will also be developed.

5 Conclusion and outlook

The initial task of linking biotechnology and wastewater treatment has been resolved to a large extent. Until now, a set of promising organisms that are potentially able to boost biogas production (and accumulate SCO, respectively) has been determined. To improve growth and SCO-accumulation of the selected microorganisms, the quality and the composition of growing media is currently optimized.

Subsequently, the performance of the organisms will be optimized with regard to ‘their’ specific substrate, using methods such as evolutionary engineering and process optimization (to generate the most appropriate variants of the strains). Both methods are not classified as ‘genetic engineering’.

Thus, it is expected that the goal of phase 1 of the subprogram (ending June 2016) – providing a set of optimized microorganisms which grow in selected wastewater streams and are able to boost biogas production and/or accumulate SCO that can be used as base chemicals – will be reached.

Based upon this, phase 2 ‘development’ of ZeroCarbFP will focus on process engineering and the integration of concepts and approaches in ‘real’ systems. This mainly applies to product line 2, where functional biomass has to be separated and accumulated SCO have to be extracted. Process engineering and pilot scale experiments can be performed at the ‘Technikum’ of the Emschergenossenschaft, a fully equipped experimental wastewater treatment plant with a capacity of 1.000 population equivalents.

Due to the interaction of subprograms, program partners and synergies already identified, the program structure of phase 2 will be adapted, accordingly.

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Algae for wastewater treatment: clean water, nutrient recovery and gaining biomass

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Abstract

In this paper first results for wastewater treatment with sedimentable algae are presented. As part of a research project a special algae culture, which sediments very fast under undisturbed conditions, was used for wastewater treatment. The high uptake rate of nutrients implies a large potential for treating wastewater. Furthermore the growth of this specific algal biomass is very high, so that in regular intervals a major part of biomass has to be harvested. This biomass can be used, e.g., for biogas production and / or nutrient recovery.

1 Introduction

Algae are ideal for innovative wastewater treatment solutions. Beside light and carbon dioxide (CO_2) they mainly need nitrogen (N) and phosphorus (P) as well as other typical plant nutrients for their growth. These nutrients are exactly the main substances which should be removed from wastewater. Algae are able to acquire them from the surrounding water and to integrate them into their biomass. In this way, the nutrients are not only removed from the water but it is also possible to recover them. Particularly with regard to the limited phosphorus resources, this will become more and more important.

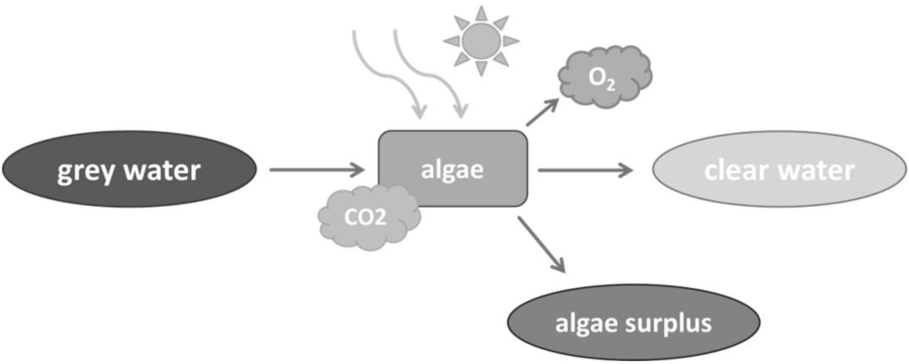

Figure 1: Wastewater treatment with algae

In addition, algae cultures are able to ingest and accumulate micropollutants, to eliminate pathogen germs, and to recover nutrients (Abdel-Raouf et al. 2012, Muñoza & Guieysse 2006).

2 Cultivation of mass algae cultures

Mixed algae populations from natural sources (small lakes, rivers, WWTP) were cultivated in photobioreactors (PBR). After a phase of selection of approx. 3 – 4 months by daily decantation of the clear water supernatant and thereby disposal of floating algae a culture of fast growing, effective nitrogen-assimilating and fast sedimenting algae was obtained. While in municipal wastewater treatment plants (WWTP) the sludge volume index (SVI) of the activated sludge is about 75 – 150 ml/g (Gujer 1999), the SVI of the selected algae sludge is about 30 – 35 ml/g without using any flocculants. Especially for harvesting purposes this low SVI is very valuable.

To supply the algae with nutrients, the water was changed daily (in a sequencing-batch-reactor-mode). Specific mixed water from a municipal WWTP with nitrogen and phosphorus concentrations very similar to greywater was used. Based on the selected algal cultures extensive experiments were started to determine several relevant factors for wastewater treatment (e. g., dry matter (DM) optimum depending on light intensity, influence of seasons, nutrient assimilation). Parameters from Table were measured regularly. During normal operation all supplied nutrients were ingested by algae within one day, so the daily morning measurements of supernatant showed most of the time very low concentrations. Exceptions occurred, when experiments with very high concentrations of nutrients were performed to show a maximal ingestion capacity of algae (see chapter 3). The parameter DM varied because of the growing and harvesting cycles that were proceeded. All physical parameters (oxygen, pH, temperature) in Table 1 show a wide range because during photosynthesis all of them are rising.

Table 1: regular measured parameters in algae culture

Parameter	Measurement intervall	Medium	Typical concentration
Dry Matter (DM)	Three times per week	Algae solution	0.2 – 2.5 %*
Organic Dry Matter (oDM)	Once per week	Algae solution	55 – 65 % of DM
Ammonium (NH_4-N)	Daily	Supernatant	depending on supplied concentration
Phosphorus (PO_4-P)	Once per week	Supernatant	
Total Nitrogen	Once per week	Supernatant	
Nitrate (NO_3-N)	Once per week	Supernatant	
Chemical Oxygen Demand (COD)	Once per week	Supernatant	
Oxygen Content (O_2)	Continuous (online)	Algae solution	6 – 60 mg/l**
pH	Continuous (online)	Algae solution	6.5 – 10.5**
Temperature	Continuous (online)	Algae solution	18 – 35 °C**

*Cycle of growing and harvesting; **Depending on photosynthetic activity during the day

The predominant genus of algae were *Scenedesmus* and *Ulothrix* (Figure 2). Sporadically other genus of algae and some bacteria were found, but always disappeared after a short time. This gives rise to the suspicion that Scenedesmus and Ulothrix are most appropriate for wastewater treatment from municipal sources – at least under the conditions given in the conducted experiments.

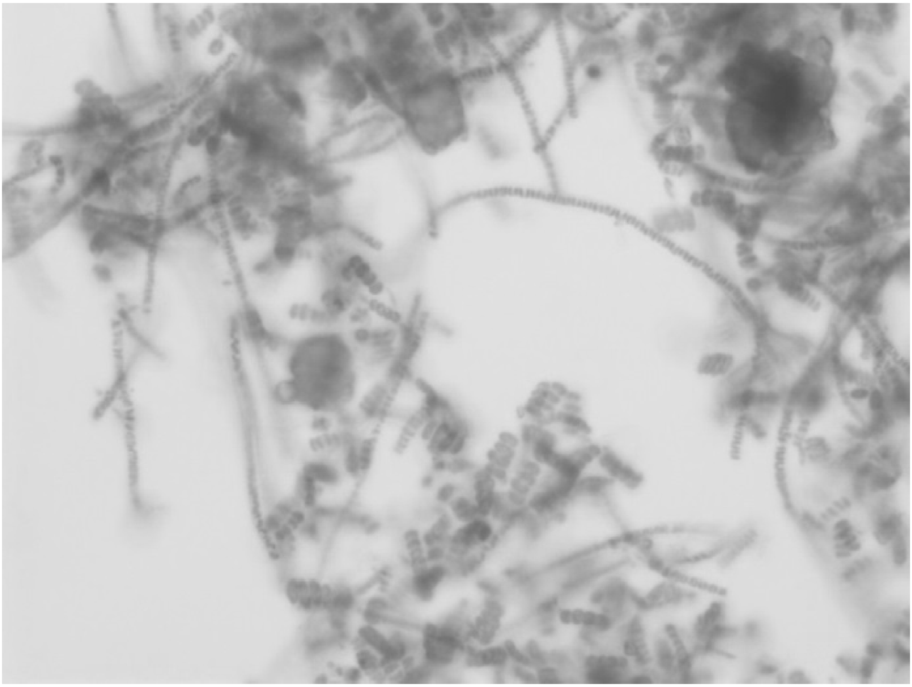

Figure 2: micrograph of *Scenedesmus* (colonial) and *Ulothrix* (filamentous)

3 Uptake rate of nutrients

For measuring the uptake rate of nutrients a defined volume of the mixed greywater with a known content of ammonium and phosphorus was added to the algae sludge in the PBR. After mixing for a few seconds the first probe was taken to measure ammonium and phosphorus (zero probe). More probes were taken after defined reaction intervals. Most of the ammonium and phosphorus was assimilated by the algae cultures during the first hour, after 2.5 hours the ingestion was nearly completed. After 5 hours the concentration of ammonium and phosphorus was lower than the measuring range (< 0.01 mg/l) (Figure 3, compare Table 1).

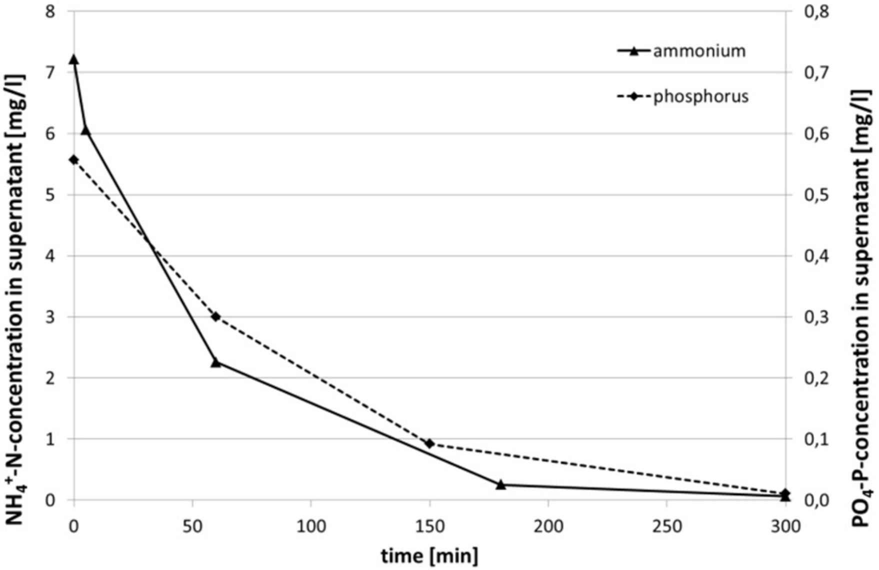

Figure 3: Uptake rate of nutrients.

For determining the absolute uptake rate of ammonium this value was measured every morning before adding new greywater. Thus the total uptake capacity of the algae sludge could be established over a periode of more than one year. As expected the uptake rate was at their highest in the summer months (April – September). But in the winter months the uptake rate was still about 25 % of the highest rate in summer (Figure 4). Based on the results it is clearly to see, that the uptake rate is depending highly on the light intensity. As April was very sunny but the following month rather cloudy, the uptake rate in April is the highest. The uptake rate in August is very low because of special experiments that were performed then. A maximum uptake rate for nitrogen was measured with 1.0 g/(m^2*d) and 0.14 g/(m^2*d) for phosphorus. This implies the opportunity of year-round operations even in northern Europe. But it also indicates that it might be possible to further optimise the uptake rate during summer.

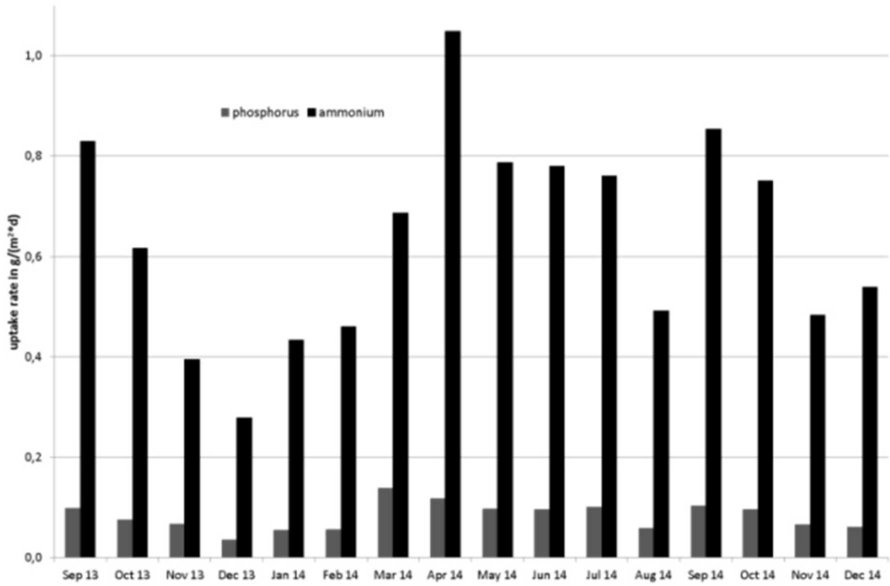

Figure 4: Total uptake of phosphorus and ammonium, daily measurements combined into mean values per month

4 Uptake rate depending on DM-content

Algae are able to maximise their light capture even under low-light conditions, so that they can optimise the photosynthetic efficiency. This causes the disadvantage, that under high solar irradiance, most of the absorbed photons are wasted as fluorescence and heat to protect against photodamage. This limits the growth of algae cultures (Mussgnug 2007). To protect against this limiting factor, an ideal DM-content in the algae cultures has to be supplied. Studies show that through mixing in photobioreactors the algae are exposed to statistical dark/light cycles. These cycles have a strong influence on photosynthetic efficiency (Posten 2009) and thus on the uptake rate of nutrients. This means, that if there is too much DM-content inside the photobioreactors an inhibition because of low-light conditions appears. If there is a too low DM-content, most of the photons are wasted. Therefore there has to be an ideal DM-content of algae for every light-intensity. To examine these limiting factors, a special series of experiments were implemented:

Four parallel PBR running under identical conditions were supplied with different amounts of algae sludge and water with low nutrient concentrations and low oxygen content. The increase of the oxygen content was measured and compared. The faster the increase of the oxygen content during the corresponding light conditions, the better is the corresponding DM-content. A slower increase indicates a limitation of the rate of photosynthesis. Based upon that, the different DM-contents were correlated to the corresponding light intensities.

By repeating these experiments many times during many different light conditions, the corresponding optimum DM concentrations for this special selected algal cultures can be determined.

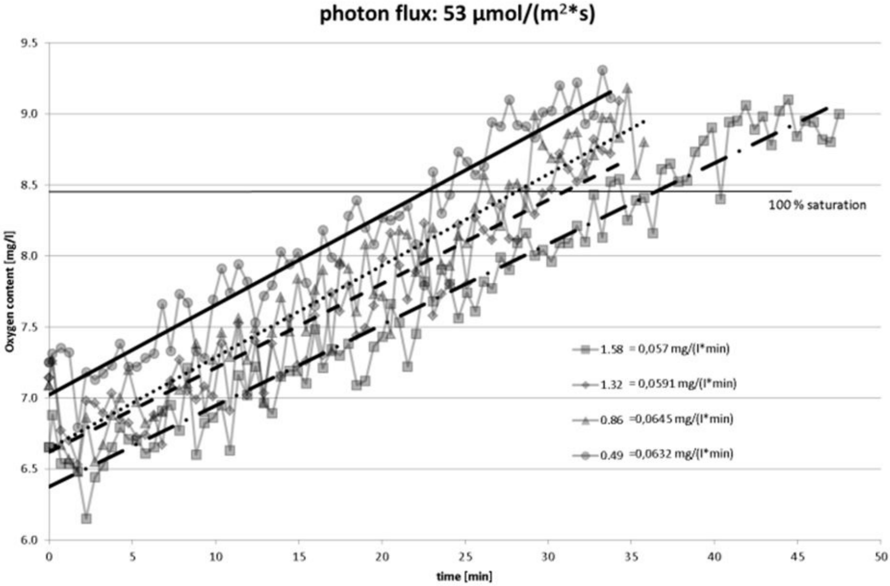

Figure 5: Determination of ideal DM-content at 53 µmol/(m^2*s)

As seen in Figure 5 one of the first experiments under low light conditions showed that the best DM-content for 53 µmol/(m^2*s) is about 0.86 g/l. The figure shows that the slope of the oxygen content (averaged with a trendline) is the fastest for the PBR with a DM-content of 0.86 g/l. For the PBR with the lower DM-content a lot of light seems to be wasted, in both PBR with the higher DM-content an inhibition seems to occur. The conclusion is, that the ideal DM-content for 53 µmol/(m^2*s) lies between 1.32 g/l and

0.49 g/l. For the next experiments under the same light conditions the DM-content for all four PBR has to be chosen in the range of these values to determine an exact DM-content.

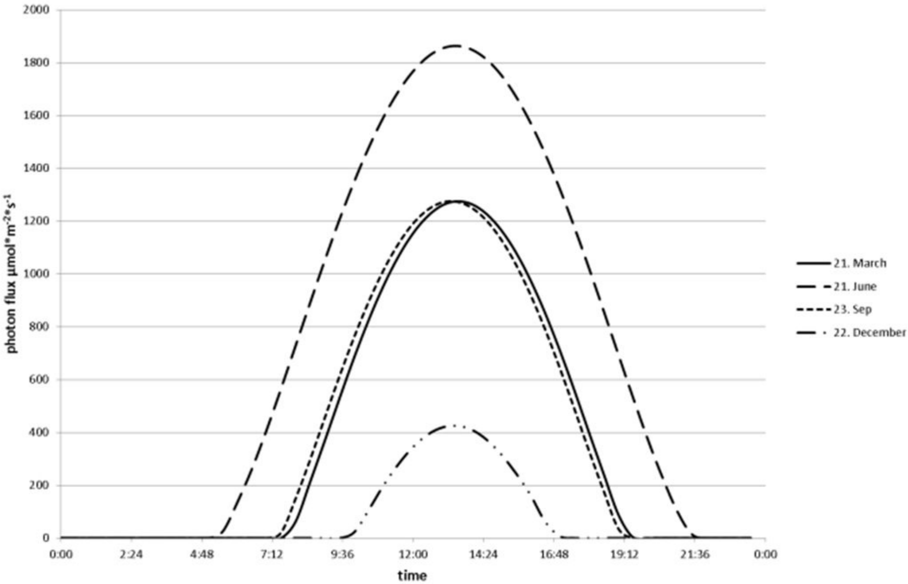

Figure 6: photon flux at clear sky in the course of the day (location: Hille, Germany) (Apogee Instruments 2014).

As seen in Figure 6Figure , the photon flux depends on the daytime and on the time of the year. Because of the correlation between the light intensity (photon flux) and the DM-content it is possible to identify the ideal DM-content for every day in the year and for every daytime. It is planned to optimise the photosynthetic efficiency to maximise the growth of biomass and uptake rate of nutrients.

5 Biogas yield

Because of the fast growth of algae, a certain amount of algae has to be harvested in regular intervals. This algae biomass does not have any further use in the wastewater treatment process. Thus it is some kind of surplus sludge, which can be used, e. g., for anaerobic fermentation.

The biogas yield was analysed in small 1 L reactors in 39 °C for 35 days in batch-tests. In the beginning an inoculum from a biogas plant, which is fed with maize, grass and manure, was used. After the first batch-test, the fermentation residue was used as an inoculum for the next batch-test in order to adapt the bacteria to the new substrate. In the first batch-tests the biogas yield increased. But after a while the biogas production collapsed (Table 2). In the second test series the algae were combined with primary sludge of a WWTP as co-substrate. Due to the background of the research project nidA200 in which brown-water shall be digested, primary sludge was chosen to replace brown-water. A co-fermentation should avoid a lack of trace elements. However, the results from the second test series show that a co-fermentation with primary sludge could not prevent the collapse in biogas production. Actually, the biogas production of the co-fermentation is even lower, possibly because of some inhibition caused by the primary sludge.

Table 2: average biogas yield

Test series	Biogas yield of algae [m^3/t oTS]	Biogas yield of co-fermentation [m^3/t oTS]
1.1	293	
1.2	317	
1.3	394	
1.4	123	
2.1	245	202
2.2	391	313
2.3	130	-

Nevertheless algae biomass can be used for biogas production. The yield is not very high, but it is still in the range of stable manure (FNR 2006). The concentration of the nutrients, especially nitrogen and phosphorus, increased strongly in the fermentation residue as compared to the greywater origin. This fermentation residue sludge is valuable for agricultural use (under the right conditions and legislations) as well as for further nutrient recovery processes such as the struvite recovery process.

6 Conclusion and outlook

The main focus of this research project is wastewater treatment for small decentralised settlements. The algae module is intended for cleaning greywater only. The growth of algae biomass and nutrition recovery are positive secondary effects.

In this context, the present results are very promising: High quantities of wastewater with low nutrient concentration can be treated effectively with mass algal cultures. Based on this, it was possible to extend the application area of this algae technology. Especially the suitability of algae as fourth cleaning stage in WWTP is examined. In this context experiments for determining the capacity of eliminating trace pollutants are planned.

By optimising all influencing factors further increases of nutrient assimilation capacity are expected with upcoming experiments, e. g., further analyses to find an optimal correlation between photon flux and DM are planned. With the ability to predict the optimal DM for every time of the day and for different seasons, for full-scale plants this DM value could be chosen automatically, due to the fast sedimentation of the algae. The surplus algae sludge can be stored in a sedimentation tank so that algae can be added or withdrawn to/from the system to reach the ideal DM-content. This can optimise the cleaning capacity as well as the nutrient recovery.

Even if it is not the main objective of the research, substantial amounts of algal biomass is produced. As the current yield is very low, there might be some possibilities to optimise the usage of algae as substrate in biogas plants. Certainly this fact is not pursued due to the aims of the research project. It has to be determined, if some other usages are more appropriate.

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SWINDON EXCEED – Aims and challenges

- A Project in the Framework of the *DAAD exceed-II* Programme -

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1 Introduction

It has become an inevitable fact that global problems centring on water resources are pervasive. It is estimated that almost 89% of the global population had access to an improved drinking water source in 2012. Nevertheless, 748 million people still lack access to an improved drinking water source. Further, one third of mankind does not have any sanitary facilities or wastewater disposal systems. Additionally, due to worldwide growth of population, the urbanisation, and industrialization of former rural areas, the demand for water resources has grown and becomes increasingly polluting. Consequently, less and less water will be available for other purposes, such as drinking water, fish farming, or irrigation. Water is undeniably at the heart of the UN Post-2015 Development Agenda that puts therefore strong emphasis on environmental protection and sustainability. Here, the sustainable use of water is one of the most important issues for development cooperation and research.

Until today unsustainable development pathways and governance failures have affected the quality of water resources, compromising their capacity to generate social and economic benefits. Demand for freshwater is growing. By 2050, global water demand is projected to increase by 55%, mainly due to growing demands from manufacturing, thermal electricity generation, and domestic and agricultural use (UN Water Report, 2015). In many cases, over-abstraction of water is the result of out-dated models of natural resources use and governance, where the use of resources for economic growth is under-regulated and undertaken without appropriate controls. Groundwater supplies are diminishing with an estimated 20% of the world´s aquifers currently over-exploited. Disruption of ecosystems through unabated urbanisation, inappropriate agricultural practices, deforestation, and pollution are among the factors undermining the environment´s capacity.

While addressing critical development challenges, particularly the lack of water supplies, wastewater treatment facilities, sanitation, and hygiene takes a huge toll on health and well-being and comes at a large financial cost, including a sizable loss of economic activity. Another, not less critical development challenge is the agricultural area. By 2050, agriculture will need to produce 60% more food globally, and 100% more in developing countries (UN Water Report, 2015). Worldwide increasing population and looming climate changes will additionally increase the challenge.

Looking at regional challenges the exploitation of water resources under sustainability aspects differs from region to region. In the Asian region, sustainability aspects are linked with progress in access to safe water and sanitation. Efforts are made to meet water demands across multiple uses and mitigating the current pollution loads and to increase resilience to water-related disasters. Regarding the Middle East region, water scarcity represents one of the urgent problems when considering water-related challenges that impede progress towards sustainable development. Unsustainable consumption and over-exploitation of surface and groundwater still contribute to water scarcity and threaten long-term sustainable development. Options being adopted to overcome these challenges include water harvesting, wastewater reuse, and solar energy desalination. With view to the Latin American region, emphasis is laid on building the formal institutional capacity to manage water resources, to bring sustainable integration of water resources management and use into socio-economic development. Within the Sub-Sahara African region, the most challenging problems are related to lack of safe water and sanitation. This, in particular, applies for overpopulated urban areas and the number of megacities. According to the UN Report “Water for a Sustainable World” (2015), only 5% of the Africa´s potential water resources are developed and average per capita storage is 200 m^3 (compared to 6,000 m^3 in North America). Further, 5% of cultivated land is irrigated and less than 10% of hydropower potential is used for electricity generation. In view of these non-utilised capacities of water resources the responsible authorities are confronted with the task to exploit and develop natural water resources without repeating the negatives experienced on the development paths of some other regions and those in developed countries.

In order to stress the dimension of no progress in sustainable development the following data may give an idea about possible consequences. By 2030, experts act on the supposition that mankind will face a 40% global water deficit under the business-as-usual scenario (2030 WRG, 2009). It is reported (USCB, 2012) that the world population is growing by about 80 million per year and is predicted to reach 9.1 billion by 2050. In view of the Sub-Saharan Africa region, 2.4 billion people will live in areas with the most heterogeneously distributed water resources (UNDESA, 2013). Additionally, in these areas the increasing population is attended by increasing urbanisation (UN Water Report, 2015).

By now, more than 50% of the world population lives in cities and projections yield urban populations that will increase to 6.3 billion by 2050 (WWAP, 2012). Here, it is expected that developing countries will account for 93% of the urbanisation globally. This puts increased pressure on the present water resources and can further exacerbate water scarcity. This, in particular, will clearly recognisable within the agricultural sector, which is already the largest user of water resources, accounting for almost 70% of all freshwater withdrawals globally (WWAP, 2014).

1.1 Scope and Goal of the SWINDON project

The overall strategic direction of the *SWINDON* project is to contribute to the shaping of future subjects and scenarios through active cooperation between developing and industrialized countries. Here, the project strategy is aligned to work on short-term successful outcomes and to assure long-term development through a sustainable network and knowledge transfer within the field of water. The knowledge transfer shall help developing sustainable strategies and tailored technical (practice-oriented) solutions to overcome urgent water-related problems, which can be aptly described as “too much, too little, too dirty”.

The overall research fields of the project comprise Sanitary Engineering, Hydrology and Hydraulic Engineering, Water Quality, Waste Management, and Water Governance. The associated competence derives from a global project network consisting of 29 full member institutions in 15 countries on 4 continents. In some regions special emphasis is laid on research fields like water quality monitoring, waste and wastewater treatment, coastal engineering, flood risk, water in agriculture and ecosystems, water food print, water loss, and water governance.

The primary goal of the SWINDON project is to promote capacity building, knowledge transfer, and to develop core proposals for sustainable water management. The latter includes technologies for manifold use and reuse of water. It is known that two thirds of fresh water worldwide is currently used in agriculture that literally drains away into the ground. Here, treated wastewater could be recycled and reused for further application, e.g. in agriculture.

2 Organisational structure and thematic orientation

The intercontinental network (Figure 1) consists of four regional centers with the participation of selected full member institutions. The TU Braunschweig (TUBS) represents the leading center and acts as contractor for the *SWINDON* project. Here, the Institute of Sanitary and Environmental Engineering with its head and project chairman Prof. Norbert Dichtl has the overall project responsibility and acts as the final decision-making body. TUBS experts and academic teachers from water sciences, water engineering, and social sciences are involved in the administration, monitoring, and evaluation of all project-related educational and research activities.

Regional coordinators represent the four regional networks. They coordinate the project activities in their respective regions and are responsible for the management and administration of its part of the project. The regional coordinators also monitor and assess the activities of the *SWINDON* project members in their regions and suggest changes concerning the status of "full" or "associated" membership.

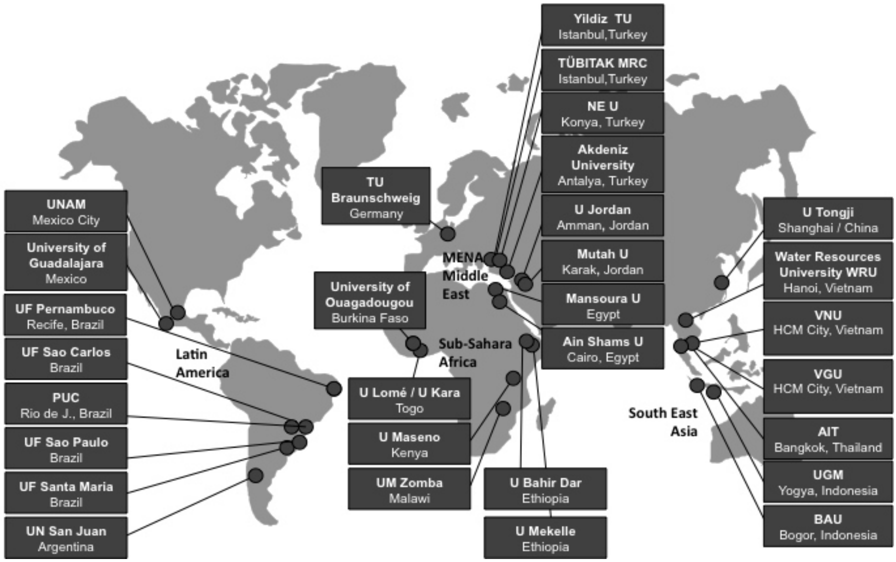

Figure 1: The project network consisting of 29 full member institutions in 15 countries on 4 continents; the full member institutions are located within four regional networks: Latin America (LA), Mediterranean /North Africa (MENA), South East Asia (SEA), Sub-Sahara Africa (SSA).

The status of membership is based on very few criteria suitable for evaluating the activities of the members. This includes the number of activities, offering university capacities, participations in workshops, number of joint publications or activities for joint research initiatives. For *SWINDON,* each regional center proposes a list of candidates for "full" and "associate" membership to the management board for final decision-making.

The main task of the full members will be to contribute actively to increase the visibility of the network while establishing contacts to other regional and international networks, and stakeholders from industry, local authorities, or state agencies. Besides this task, full members also have the responsibility to work on structures and measures assuring the stability and the financial sustainability of the regional and the entire *SWINDON* network. A measure for assessing the success will be the type, quality, and number of cooperation and research initiatives with members from universities, companies, and/or state agencies.

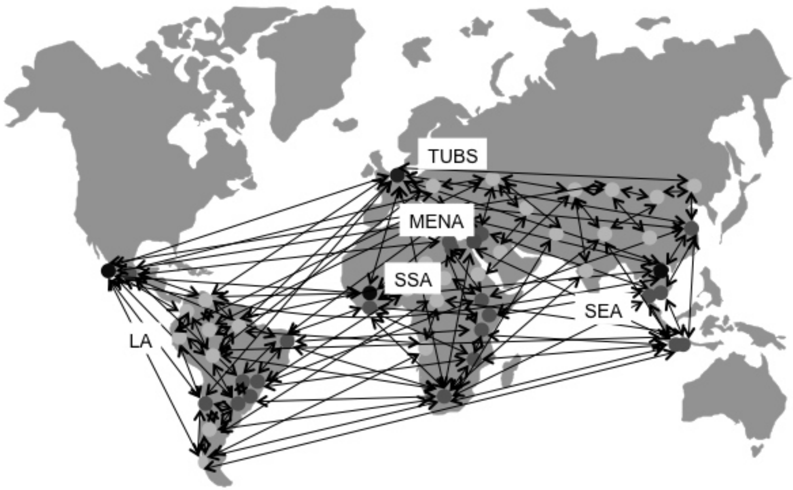

Figure 2: Project network comprising full and associate members.

The concept of associated membership is further to contribute to *(i)* internationalisation at the *SWINDON* member institutions and, *(ii)* to improve the performance of, the capacity building at and the knowledge transfer between the member institutions. This concept is expected to create a close grid of interacting members (Figure 2) who are able to contribute to the stabilization and sustainability of the entire network by the sum of their expertise and capacity.

The *SWINDON* project focuses its activities on MDG 7 and on UN Post-2015 Agenda. The concept of Sustainable Development Goals (SDGs) was born at the United Nations Conference on Sustainable Development, Rio+20, in 2012. The objective is to produce a set of universally applicable goals that balances the three dimensions of sustainable development: the environmental, social, and economic.

With respect to the project activities, these are embedded in project areas like capacity building, higher education, knowledge transfer, networking, and research. Special attention is paid to strategic objectives comprising network effectiveness, visibility, and network sustainability. The network effectiveness is determined by comparing the clearly formulated target-setting with the actually achieved outputs and outcomes of the respective project measure. For example, a clear link (red thread) between the thematic orientation and the output and outcome of an expert workshop must be recognisable. This shall also be applicable to all project measures (Table 1).

Table 1: Project areas and measures

Areas	Measures	
▪ Network ▪ Capacity Building / Higher Education ▪ Knowledge Transfer ▪ Joint Research	▪ Summer schools ▪ Expert Workshops ▪ Regional Meetings ▪ Training Courses ▪ Exchange of Graduates	▪ Teacher Exchanges ▪ Management Board Meetings ▪ Coordination Trips ▪ Joint Research Proposals

3 Problems and challenges within the network regions

Latin America

In this region, the basis of most economies remains the export of natural resources, which use large quantities of water in production. This situation puts pressure on water management as economic activities and population tend to be concentrated in dry and sub-humid areas which again leads to increasing competition in terms of quantity, but also more recently in terms of quality and opportunity of use for scarce water resources. This situation is expected to get worse through joint negative effects of higher water demands due to population growth and economic development coupled with drier conditions and increased hydrological variability in many river basins because of changing climate conditions. Overall, these tensions highlight two water-related priorities that countries in this region will have to address in the coming decades: (i) strengthening water governance and (ii) improving provision of drinking water supply, sanitation services, and sufficient wastewater treatment capacities (UN Water Report, 2015).

The levels of provision of water, wastewater treatment facilities, and sanitation achieved in the region might be compared to those in other developing countries in other regions. Especially, considering the provision of water, serious deficiencies in service quality (intermittence, water losses, water quality control, etc.) disproportionally affect rural areas and the poor. Many cities still suffer from episodic flooding because of inadequate stormwater drainage infrastructure and deficiencies in urban planning (WWAP, 2012).

Middle East /Arab Region

Water scarcity stands at the forefront when considering the water-related challenges that impede progress towards sustainable development in the Middle East/Arab region.

Other important challenges include the need for more sustainable water use, access to more reliable water services (not at least with least developed countries and countries suffering directly and indirectly from conflict), and improved water governance for national and transboundary surface water and groundwater resources.

It must further be added that population growth and increasing socio-economic pressure have contributed to worrying reduction of available freshwater resources.

Availability dropped from 921 m^3 per capita per year in 2002 to 727 m^3 per capita per in 2012, with 16 of 22 Middle East/Arab countries falling below the water scarcity level of 1,000 m^3 per capita per year and able to withdraw on average only 292 m^3 per capita per year in 2011 (UN Water Report, 2015). In addition, drought affects over two-thirds of the land area in the region.

Threads to sustainability mainly concern unsustainable consumption and over-extraction of freshwater resources. Further, on average, the agricultural sector continues to be the greatest consumer of water in the region.

In total the challenging problems face increasing freshwater shortages due to drought, water distribution losses, agriculture, damage to water infrastructure and networks due to armed conflicts, and increasing energy costs associated with pumping water from more distant or deeper sources (e.g. fossil groundwater).

South East Asian Region

It cannot be overlooked that the heavily populated Asian region faces challenges associated with water-related disaster risks in the context of climate change, accelerated urbanisation, wastewater treatment and sanitation, and the quality and quantity of available water supplies.

Some progress has been made in terms of access to improved drinking water (people using improved water supplies increased by 19% Southern Asia and 23% in Eastern Asia between 1990 and 2012). Nearly 1.7 billion people in the region (with more than half of these living in rural areas) still did not have access to improved sanitation in 2012 (WHO and UNICEF, 2014).

In the region, changing weather conditions are likely to increase the incidence and severity of extreme events, with some projections including an increase in the frequency of years with above normal monsoon rainfall or extremely low rainfall (IPCC, 2014). Melting glaciers will affect water supplies, creating risks of glacial lake outburst floods and downstream flooding for some regions, and in the long-term leading to an overall reduction in water supplies from snow cover and glacial runoff (World Bank, 2013). Over the long-term, drought will become an even more serious concern, particularly given the already strained water access issues (IPCC, 2013).

On political level, Governments have been working towards making their countries and societies more resilient, but much more work is needed. In many countries, national policies are not well implemented, measures to protect the most vulnerable are often lacking, and institutional capacity to handle disasters are at times still weak. Further, the Asian region is one of the most rapidly urbanizing regions in the world, with 2.4% annual growth of the urban population. In 2012, 47,5% of the total population (over 2 billion) lived in urban areas. By 2015, it is estimated that 2.7 billion people will be living in urban areas placing considerable stress on the water resource base of the region's cities (UN Water Report, 2015).

In total the big challenges in the region face drinking water supply (compounded by a high proportion of water loss in distribution), water quality control, limited coverage of sewerage networks and (often non-existing) wastewater treatment systems, pollution control, and ecosystem degradation, especially in peri-urban areas and in surrounding river basins.

Sub-Sahara Africa

The basis of many economies in the region is agriculture, depending on highly variable and unpredictable rainfall events. A major constraint in sustainable agricultural production is assured and timely water availability.

Africa´s population, compared to other regions around the globe, is rapidly growing and reaches fertility rate above those needed to replace current populations. This population must be fed, educated, and kept healthy and productive. It is in this context the water for food, water for health, and water for energy that is critical to sustainable development. Nevertheless, remarkable progress has been made towards attaining improved drinking water (except for the most fragile states), especially for urban populations, but much less, progress has been made with respect to sanitation (UN Water Report, 2015).

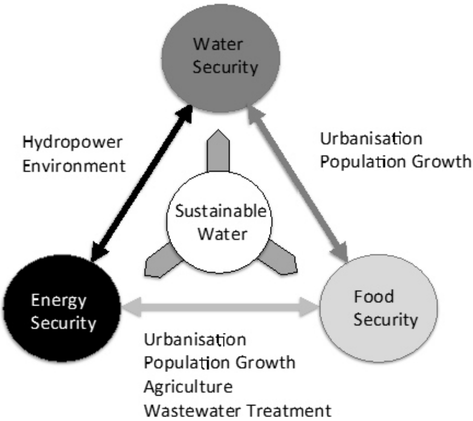

Figure 3: critical nexus between water, food, and energy in Africa.

The critical nexus between water, food, and energy (Figure 3) is of particular importance. For Africa water availability, access and optimal use are essential for transforming the vicious cycle of insecurities to a virtuous one. Currently, only 5% of the Africa's potential water resources are developed and average per capita storage is 200 m^3 compared to 6,000 m^3 in North America. Only 5% of Africa's cultivated land is irrigated and less than 10% of hydropower potential is utilized for electricity generation (Sperling and Bahri, 2014).

Considering the above statistics, regional cooperation is especially needed due to the multiplicity of transboundary water resources (more than 80 international river basins and aquifers; UN Water Report, 2015) that must be managed coherently and equitably to meet regional and national goals.

In total, the most important and critical corner points that relate to sustainable development in Africa are: (1) Water infrastructure for economic growth, (2) Managing and protecting water resources, (3) Achieving water supply and sanitation MDGs, (4) Global changes and risk management in Africa, (5) Water governance and management, (6) Financing water and sanitation sector, and (7) Education, knowledge, capacity development, and water information.

4 Challenges with regard to the project and network

Water-related problems worldwide, however, in developing countries in particular, are manifold and represent a multi-criteria problem. All efforts to solve the most severe and crushing problems as well as the sustainable impact of initiated measures lag behind the fast growing population and changing climate conditions. There will therefore be no all-encompassing solution; only timely and locally restricted solutions might have a realistic chance. The concentration on what is most crucial and urgent in the solution of local challenges seems to be more promising. This is what the Swindon project lays emphasis on; the cooperation with partners within a tightened network where the integrated regional network concentrate on specific regional problems. The expertise of the regional experts and their higher education institutions can be individually linked and applied to solve most acute problems. The experiences achieved will be available for the other regional networks that maybe eventually dealing with similar problems (transregional communication and problem solving).

Since the water used is mainly drawn from the aquifer, the result is a drawdown with drastic consequences, such as desertification in semi-arid regions or ground instability and subsidence in megacities. Water is scarce also in the seemingly water-rich regions of the world. An unregulated use of fresh water and insufficient treatment of wastewater from industry and households lead to the pollution of inland and coastal waters, degrades them ecologically, renders them useless for other forms of utilisation, and also causes diseases in many cases. Countries in Southeast Asia are confronted with yet another problem, which constrains the utilisation of available water. The Mekong, as one of the largest rivers in the world, as well as several other rivers of the region, flows from the Himalayan region. Due to processes of climate change, increased melting of glaciers contributes to natural erosion. Toxic heavy metals ions and metalloids like arsenic are washed out to a considerable extent, thus contaminating the surface and ground waters of countries as far away as Vietnam. The low rate of sewage water treatment (which is, for instance, also a problem in Africa and Latin America) adds to the problem, rendering fresh water supply and sewage water disposal significant environmental and health risks.

Further, in regions where even and fair water distribution is an additional problem to water scarcity and water pollution, the political and socio-economic aspects join alongside the natural and engineering science disciplines. After all, most of the worldwide biggest rivers flow through more than one country. In the light of this fact, the trans-national interdisciplinary treatment of water-related problems is obvious and inevitable. For that reason, the research activities among the network members also concentrate on interdisciplinary cooperation.

The Swindon project has defined five research fields that are Sanitary Engineering, Hydrology and Hydraulic Engineering, Water Quality, Waste Management, and Water Governance. In order to work effectively together within these research fields expert working groups are created. That´s why each regional network has named experts who have been assigned to the above mentioned research fields. Additionally, each regional network has listed within two categories (traditional research fields/technologies and present/virulent and future research fields and technologies) the topics that are represented by the respective experts. This matrix facilitates joint international cooperation and opens opportunities to define specific target topics for joint research initiatives. Here, the focus will be on tailor-made concepts that deal with specific water-related problems and practice-oriented solutions.

Table 2: Specific challenges/problems within the regional networks

- Wastewater treatment capacities	- Water-related disasters (flooding, ...)
- Sanitation	- Water-related deseases
- Waster in agriculture (reuse, irrigation)	- Water quality (monitoring, pollution control)
- Water loss	- Drainage infrastructure
- Water scarcity	- Water management
- Water infrastructure	(river basin, urban supply, freshwater resources, overextraction)
	- Transboundary water problems
	(dams/hydropower)
	- Lack of educated / trained staff

The main specific challenges and problems that are reported by the four regional networks can be seen in Table 2. The priority may be different from one another but in some cases, the problem areas could overlap. In these areas, the demand for practice-oriented solutions is comparatively high. However, in most developing countries the willingness of state or local authorities for introducing sustainable changes is often low or not in place. Sometimes, money is also missing or measures are under-regulated and undertaken without appropriate control. What is needed, are demand-oriented, applicable (practice-oriented), and economically applicable solutions. The lack of educated and trained staff for ensuring a sustainable and reliable operation of installed technologies and the practical implementation of water-problem-solving management strategies is, not least, one of the most burning problem (e.g. in Africa).

Finally, referred to the thematic conference contributions, three overall problem fields can be recognized that also meet common thematic points and problems of the regional networks within the SWINDON project (Figure 4).

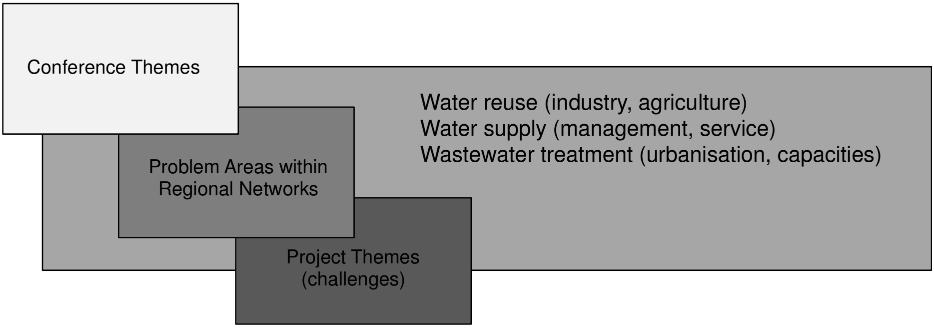

Figure 4: Main common thematic points (conference, regional networks, Swindon project)

5 Concluding Remark

Growing demands, according to overpopulation, and misuse of water resources have augmented the risks of water pollution and severe water stress. It can be observed that the time span between catastrophic events is becoming shorter and shorter. Moreover, the intensity of local water crises has been increasing, with serious implications on health, ecosystems, food and energy security, and economic development.

Although the growing recognition that water plays an irreplaceable role in sustainable development, resources water management and provision of water-related services remain far too low on the scales of public perception and governmental priorities. As a result, water often becomes a limiting factor, rather than a contributor, to social welfare, economic development, and healthy ecosystems. Principally, enough water is available to tackle the growing demand. However, the most important problem is the dramatically changing the way water is used, managed, and shared.

To put it concisely: the augmenting water crisis to a large extent can be attributed to governance, likely more than to resource availability, However, it must be laid emphasis on establishing effective strategies for sustainable water management which should have a lasting impact on a water secure world.

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